(E83-10081) DEVELOPMENT OF TECHNIQUES FOR PRODUCING STATIC STRATA MAPS AND DEVELOPMENT OF PHOTOINTERPRETIVE METHODS BASED ON MULTITEMPORAL LANDSAT DATA Final Report, 15 Nov. 1976 - 14 Dec. 1977 (California Univ.) N83-27284 Unclas G3/43 00081

SPACE SCIENCES LABORATORY

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FINAL REPORT

for

NASA CONTRACT NAS9-14565

Period Covered

15 November 1976 to 14 December 1977

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Principal Investigator: Robert N. Colwell
Project Scientists: Claire M. Hay (Project Manager)
Randall W. Thomas

December 1977
Remote Sensing Research Program
Space Sciences Laboratory
Series 19, Issue 1

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Berkeley, California 94720

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DEVELOPMENT OF TECHNIQUES FOR PRODUCING STATIC STRATA MAPS AND DEVELOPMENT OF PHOTOINTERPRETIVE METHODS BASED ON MULTITEMPORAL LANDSAT DATA

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SECTION 1.0:

STATIC STRATIFICATION FOR SIGNATURE EXTENSION

R.W. Thomas and J. Claydon

1.0 TASK I: STATIC STRATIFICATION FOR SIGNATURE EXTENSION

1.1 OBJECTIVE

The objective of this task was to evaluate and if necessary improve the signature extension stratification maps developed by UCB in previous LACIE tasks. Specifically, the ability of the strata to group spectrally similar wheat subclasses was to be evaluated. In order to understand the physical cause of the strata grouping patterns, a number of climatic, soil and Landsat pass-specific variables were analyzed with regard to their influence on the spectral signature of wheat.

1.2 GENERAL APPROACH

The task, designed to evaluate the statistical significance of the static stratification and to provide information for its refinement, was divided into two subtasks. These were (1) to evaluate through Hotelling's T^2 statistic the static stratifications' ability to group spectrally similar areas in order to maximize signature extension success and (2) to determine the statistically significant signature controlling variables for use in refining the stratification procedure.

SUBTASK A: STRATA GROUPING ANALYSIS

The purpose of this subtask was to determine if the static stratification did in fact isolate areas tending to have similar wheat sigatures. This analysis was also intended to discover the extent to which individual strata could be grouped together and still provide for potentially successful signature extension.

The final experimental procedure was composed of five basic parts. The first, preprocessing, standardized segments to a common sun elevation and haze condition. This was accomplished by implementation of XSTAR haze correction procedures (Lambeck 1977) developed at ERIM. Preprocessing in this case provided a more stable measurement frame (Landsat or Tasselled Cap Space) and thereby increased the ease with which real spectral differences could be identified and evaluated.

Each sample segment was partitioned according to land use-soil association strata as defined by the UCB static stratification. Each segment partition was then individually clustered in a single date mode by ISOCLAS (adapted from JSC). The clustering process was limited to ten iterations, a maximum band standard deviation of 3.2 Landsat counts within a cluster, and distance between clusters of 3.2.

Resulting clusters from each segment by UCB stratum were then stratified or grouped according to the percent wheat within the clusters. This was accomplished by ocularly comparing the cluster map with corresponding Blind Site ground data maps. In order to minimize the time required in this cluster grouping process, clusters were ordered (highest

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to lowest) by their 2 x Band 7 to Band 5 ratios of the cluster means on the Landsat pass-date in question. This ratio was used as an indicator of vegetation and, depending on the date and state, of wheat versus other crop types. Using an interactive color TV monitor system, clusters having the higher Band 7 to 5 ratios were displayed and analyzed first, followed by clusters having lower ratios down to the non-live vegetation or "soil line" (1.0 - 1.10) (See unlabelled cluster display procedure description in Section 2.0.) In this way the multiple clusters occurring within fields could be "reconstructed" into field patterns and strongly correlated crop type patterns on the initially blacked-out TV screen. The proportion of wheat in a given cluster could then be readily judged according to its distribution among fields. Four basic percent wheat cluster groups were established: 75-100%, 50-<75%, 25-<50%, and 0-<25%. Information was also recorded regarding the cover type makeup of the non-wheat portion of each cluster group.

A random sample of pixels were labelled from the cluster groups comprising 75-100% and 50-<75% wheat in each stratum of each segment on each date. A random number generator operated through the interactive color display system minimized the time required for pixel selection. Ten to fifteen pixels in each of the two cluster groups were labelled as to crop type using the JSC Blind Site ground data maps. This labelled pixel sample served three purposes: (1) it served as a check on the ocular estimate of percent wheat for each cluster group; (2) it provided the data employed in the Hotelling's T^2 test of wheat spectral difference between all possible pairs of land use/soil/climatic strata sampled; and (3) it provided the wheat pixel data used in the spectral sensitivity analysis (Subtask B).

*The final, or fifth step, in the strata grouping analysis was to perform pairwise spectral comparisons of wheat signature between all possible combinations of the land use/soil/climatic strata sampled. These comparisons were made by applying Hotelling's T^2 test to the four channel Landsat wheat signatures obtained from each pair of strata. Three sources of wheat signature data were evaluated separately: (1) the sample of pixels from the 75-100% wheat cluster group; (2) the sample of pixels from the 50-<75% wheat cluster group; and (3) the combined sample of pixels from the 75-100% and 50-<75% wheat cluster groups obtained in each stratum in each segment. Comparisons were limited to the same state and same biostage.**

The result of the Hotelling test was a statistical significance or alpha value which gave the probability that the observed wheat signatures came from the same population. Alpha values of .05 (5 times in 100) or less were interpreted to mean that the null hypothesis of no significant spectral difference between wheat signatures was to be rejected for the given pair of strata in question. By noting which pairs of strata did not cause rejection of the null hypothesis, sets of strata having statistically similar wheat signatures could be defined. Furthermore, it was assumed that non-rejection of the null hypothesis of spectral

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**For purposes of this analysis a given biostage was considered to be extended over the several days included in the data set.*

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similarily implied a high probability of acceptable wheat classification performance. That is, if wheat spectral models (training statistics - mean vector, covariance matrix) obtained from one portion of a set of spectrally similar strata were used to classify (using quadratic or linear discriminannt functions) the remaining portion of that strata set, an overall acceptable level of classification performance would be obtained. Acceptable as used here is defined relative to the classification accuracy obtained by classifying based on local strata training statistics.

SUBTASK B: SIGNATURE CONTROLLING FACTOR SENSITIVITY ANALYSIS

This subtask differed from the first in that the cause for signature variability was explored. The basic approach was to develop regression relationships relating spectral reflectance (dependent variable) to a set of static stratification, seasonal, and date-specific predictor variables. Matched spectral response and predictor variable data were obtained for all pixels sampled in the grouping analysis (Subtask A). The signature predictor variable set is described in Table 1.1. This list has been revised from earlier work (Hay et al. 1977b) to incorporate measures of evapotranspiration stress and available soil moisture.

The relative importance of each signature predictor variable listed in Table 1.1 was expressed two ways. Measure #1 consisted of the percent of total spectral variance (by band) explained by the addition of a given predictor variable to the regression equation. Variables were added in the same order as listed in Table 1.1 using a stepwise regression technique. The order - static, seasonal, date-specific - was chosen to most effectively identify the percent spectral variance accounted for by the static stratification variables before application of a signature extension algorithm. The R^2 (multiple correlation coefficient squared) increments, representing the percent of variance added by each variable, were highly dependent on this ordering.

The second measure of signature predictor variable importance did not employ a pre-specified order of entry into the regression. A forward selection regression procedure* was used to order variables and tabulate the R^2 increments. Using this technique, the predictor variable having the highest simple correlation with the spectral band in question was entered into the regression first. The next variable entered was the one having the highest partial correlation with the spectral band after the effect of the first variable entered was removed from both the dependent and independent varables. The third variable entered had the next highest partial correlation with the spectral response variable among all remaining predictor variables with the effects of the first two variables removed, and so on. Order of entry for a given variable among all bands for a given date provide the second measure of performance.

Both Landsat bands and Tasselled Cap (Kauth) bands were used as the dependent signature variables in the regression. Tasselled Cap bands are formed by a rotation of the Landsat coordinate system by date to

*As implemented by the Statistical Package for the Social Sciences (SPSS).

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Table 1.1: Signature Predictor Variables Used in the Kansas and North Dakota Wheat Spectral Sensitivity Analysis

Predictor Variables	Measurement Technique Used for Each Field Sampled
I. STATIC STRATIFICATION VARIABLES (Obtained from Static Strata map)	
A. Cultivated area percent (CULTPCT)	Midpoint of cultivated area percent range for the land use class covering the wheat field
B. Soil available water holding capacity (AWC)	Average inches of water held per inch of soil at field capacity in the top 24 inches for the static strata soil assoication covering the wheat field. These values are obtained from information available in county soil survey publications.
C. Long term average growing season degree-days (LTGSDD)	Midpoint of growing season degree-day class covering the wheat field. Degree-day classes obtained from 30 year average data by automatic and manual interpolation of ground meteorological station data for the period April through June in Kansas and June through August in North Dakota.
D. Long term average growing season precipitation (LTGSP)	Midpoint of growing season precipitation class covering the wheat field. Precipitation classes obtained from 30 year average data by automatic and manual interpolation of ground meteorological data for the period April through June in Kansas and June through August in North Dakota.
E. Long term potential average available water in top two feet of soil. (24xAWC) X LTGSP	Multiply previously obtained values of AWC and LTGSP.
F. Long term growing season evapotranspiration (LTGSET)	Substitute 5-year average values for pan evaporation from nearest ground meteorological station making this measurement. Alternatively, empirical models using temperature and solar radiation may give satisfactory evapotranspiration estimates. Currently only pan data is utilized here.

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Table 1.1 (cont'd)

Predictor Variables	*Measurement Technique Used for Each Field Sampled*
G. Long term evapotranspiration stress on soil moisture reserve *(24xAWC) X LTGSET*	*Multiply previously obtained values AWC and LTGSET.*
II. SEASONAL VARIABLES (Specific to 1975-76 Growing Season)	
A. Robertson Biostage or Bionumber *A numerical measure of crop development based on daily maximum and minimum temperature at selected meteorological stations in LACIE counties.*	*Data obtained from Robertson biostage isoline maps reported for the Great Plains in the Weekly Meteorological Summaries produced in LACIE.* *The Robertson system divides the biological stages of wheat into seven development phases: 1) planting; 2) emergence; 3) jointing; 4) heading; 5) soft dough (turning greenish yellow to yellow); 6) hard dough; and 7) harvest. A Robertson number of 4.0 would mean that 50% of the crop is headed. Robertson numbers used in the sensitivity analysis were recorded to the nearest .1 of a development phase.*
B. Growing Season degree-days accumulated to Landsat pass-date *(SUMGSDD)*	*Calculated from temperature data supplied from nearest ground meteorological station having a physical/climatic setting most closely approximating the segment in which the wheat field falls. Growing season period: April through June (Kansas) May through August (North Dakota).*
C. Growing season precipitation accumulated to Landsat pass-date *(SUMGSP)*	*Determined as in II.B, relative to to precipitation data.*
D. Growing season potential available soil water in top 2 feet of soil column *(24xAWC) X SUMGSP*	*Multiply previously obtained values for AWC and SUMGSP.*
E. Growing season evapotranspiration accumulated to Landsat pass-date (SUMGSPET)	*Substitute growing season sum of pan evapotranspiration data from nearest station making this measurement.*

Table 1.1 (cont'd)

F. Growing season measure of available soil moisture in top 2 feet of soil (24xAWC X SUMGSP) ÷ SUMGSET = potential available soil water-evapotranspiration loss	Use values for AWC, SUMGSP, and SUMGSET obtained previously. Note that ground water table (a water source) is assumed not to be near the soil surface.
G. Average January 1976 temperature (JANTEMPT)	Determined from nearest meteorological station as in II.B.
H. Planting season degree-days accumulated to Landsat pass-date (SUMPSDD)	Determined as in II.B. but for the period September through November (Kansas) and April (North Dakota).
I. Planting season precipitation accumulated to Landsat pass-date (SUMPSP)	Determined as in II.B. relative to precipitation data in the period August through November (Kansas) and April (North Dakota).
III. LANDSAT DATE-SPECIFIC VARIABLES	
A. Precipitation in the four days preceding Landsat pass-date (PPT4DA)	Determined as in II.B. relative to precipitation data.
B. 100X Tangent of Landsat scan angle (SCANANG)	Departure measured along scan line of segment relative to an imaginary base line perpendicular to the scan direction and passing through the Landsat full frame center point. Measurement based on full frame center point longitude and latitude coordinates given in Landsat Cumulative U.S. Standard Catalog and on sample segment coordinates supplied by JSC. The departure, reported in nautical miles, is defined as zero on the base line and increases positively to the east and negatively to the west. Then $\tan(\text{scan angle}) = \dfrac{\text{departure (n.m.)}}{\text{mean sat. altitude (494 n.m.)}}$
C. Landsat Band 7 to Band 5 ratio (RASF) This ratio is one real-time indicator of biostage.	Obtain (2x) Band 7 to (1x) Band 5 ratio for the pixel.

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to give four new bands (see Figure 1.1). The first of these bands is oriented along what is termed a (soil) brightness axis, darker surface reflectances having lower band values. A greeness band (Band 2) is defined perpendicular to the first. This channel has been found to behave largely as a function of crop state and leaf area index. Consequently, as crops move through their life cycle they tend to trace a particular trajectory (the "Cap") in the brightness-greeness plane depending on the initial soil brightness at the time of planting or emergence. A third dimension, yellow, is next defined perpendicular to the brightness-greeness plane. To date, this band has been used as a haze correction diagnostic (Lambeck 1977) and has also been suggested to be related to senecing vegetation. In this latter case, vegetation as it matures is hypothesized to move slightly out of the brightness-greeness plane and "roll over," thus forming the very top of the cap. Near and after harvest the crop's trajectory, or more exactly the individual trajectories of the field representatives of the crop, in the brightness-greeness-yellow space proceed back to their particular soil brightness regions from whence they started, thus forming the cap's "tassels." A fourth dimension is defined perpendicular to the hyperplane or space of the first three. This dimension contains only a small percentage of the total spectral variance, largely noise, and has as yet to be related to crop cycle parameters. See Kauth and Thomas, 1976b, for a complete discussion of Tasselled Cap Space.

1.3 DATA SET

Two biophase periods were selected in Kansas and North Dakota in which to apply the grouping and sensitivity analysis procedures just described. Date #1 in both states represented a wheat emergence condition. The second date corresponded approximately to a jointing or advance jointing condition for the wheat crop. These time periods were selected based on sensitivity analysis results reported earlier (Hay et al. 1977a) which suggested that these stages were most difficult to characterize by static stratification variables. This analysis was therefore considered conservative relative to the performance of the static stratification. Available sample segments were limited to those 1976 LACIE blind sites having ground data to minimize incorrect interpretation of results. Tables 1.2 and 1.3 list the sample segments, dates, and land use/soil/climatic strata sampled. Figures 1.2 and 1.3 display the location of the climatic strata utilized in the grouping analysis.

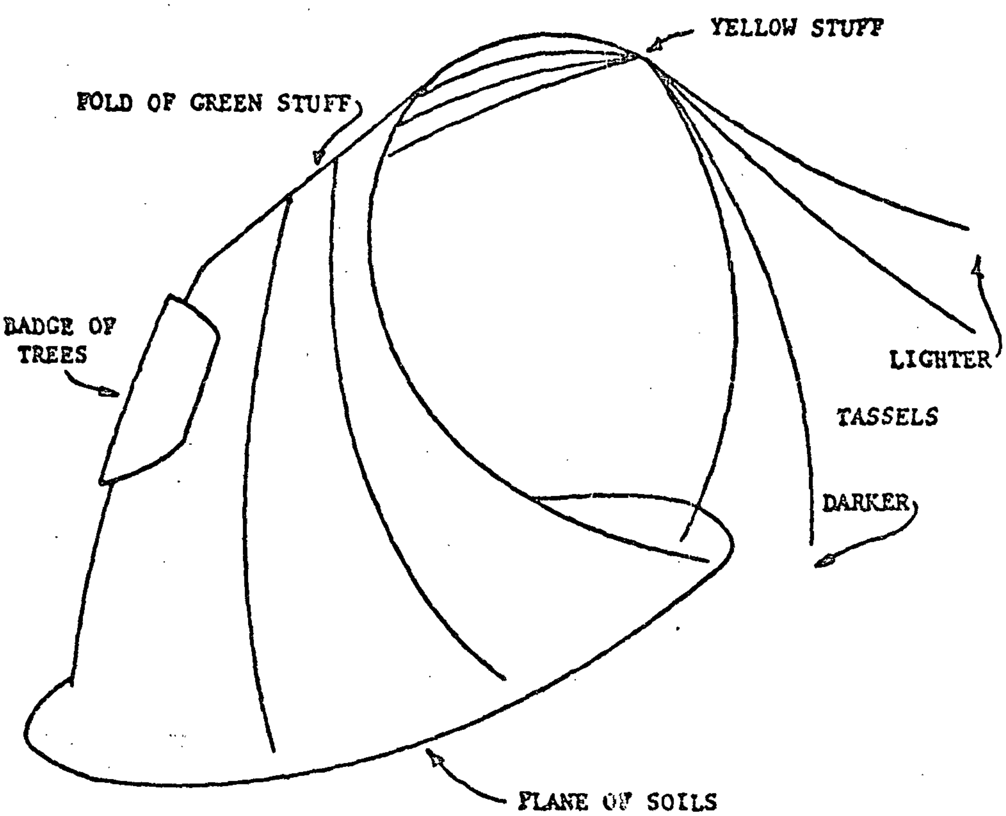

Figure 1.1. The Tasselled Cap (Kauth and Thomas 1976a)

Table 1.2: 1976 Blind Site Data Set Used in Kansas for Grouping and Sensitivity Analysis

Segment	Date	Land Use/ Soils Stratum*	L.T. Degree-Day/ Precip. Stratum*	Segment	Date	Land Use/ Soils Stratum*	L.T. Degree-Day/ Precip. Stratum
1019	1-19	212/72A	1900-2050D.D./ 8-9.5 inches	1020	5-7	211-3/88C & 212/93C	1900-2050D.D./ 8-9.5 inches
1851	1-19	211/70N	"	1171	5-4	211/50B & C	2200-2350/D.D./ >11 inches
1851	1-19	310/75G	"	1171	5-4	211/56A	"
1855	1-19	220/75F	1900-2050D.D./ 9.5-11 inches	1855	5-6	220/75F	1900-2050D.D./ 9.5-11 inches
1855	1-19	310-75G	"	1860	5-6	211/65C	2200-2350D.D./ 8-9.5 inches
1857	1-20	211-2/88A	"	1860	5-6	211-70B	"
1857	1-20	212-3/104A	"	1860	5-6	212-3/75A	"
1857	1-20	310/181A	"	1861	5-7	211-3/88A	1900-2050D.D./ 7-8 inches
1861	1-20	211-3/88A	1900-2050D.D./ 7-8 inches	1880	5-6	220/75F	1900-2050 D.D./ 9.5-11 inches
1880	1-18	220/75F	1900-2050D.D./ 9.5-11 inches				
1882	1-18	220/54A	2200-2350D.D./ 9.5-11 inches				
1891	1-18	220/139A	2200-2350D.D./ 9.5-11 inches				

*Appendix A gives a description of the land use/soil codes. A discussion is given in Hay and Thomas 1976a.

Table 1.3: 1976 Blind Site Data Set Used in North Dakota for Grouping and Sensitivity Analysis

Segment	Date	Land Use/ Soils Stratum*	L.T. Degree-Day/ Precip. Stratum	Segment	Date	Land Use/ Soils Stratum*	L.T. Degree-Day/ Precip. Stratum
1618	5-24	211/7E	2440-2480D.D./ 8.8-9.0 inches	1614	7-1	211/7L	2360-2400D.D./ 8.4-8.6 inches
1618	5-24	212/7N	"				
1624	5-25	211/7G	"	1614	7-1	212/16G	"
1633	5-26	211/14D	2400-2440D.D./ 8.6-8.8 inches	1618	6-30	211/7E	2440-2480D.D./ 8.8-9.0 inches
1642	5-24	211/7D	2480-2520D.D./ 9.0-9.2 inches				
1642	5-24	211/15C	"	1633	6-30	211/14D	2400-2440D.D./ 8.6-8.8 inches
1642	5-24	212/15P	"	1642	6-30	211/7D	2480-2520D.D./ 9.0-9.2 inches
1650	5-27	220/30E	2400-2440D.D.; 8.0-8.2 inches	1642	6-30	211/15C	"
1651	5-28	212/24H	2440-2480D.D./ 8.0-8.2 inches	1642	6-30	211/15O	"
1660	5-26	220/32A	2440-2480D.D./ 8.6-8.8 inches	1642	6-30	212/15P	"
1660	5-26	212/23C	"	1656	7-2	220/35J	2440-2480D.D./ 8.2-8.4 inches
1662	5-24	211/15A	2480-2520D.D./ 8.8-9.0 inches				
1662	5-24	212/10I	"				

*Appendix A gives a description of the land use/soil codes. A discussion is given in Hay and Thomas 1976b.

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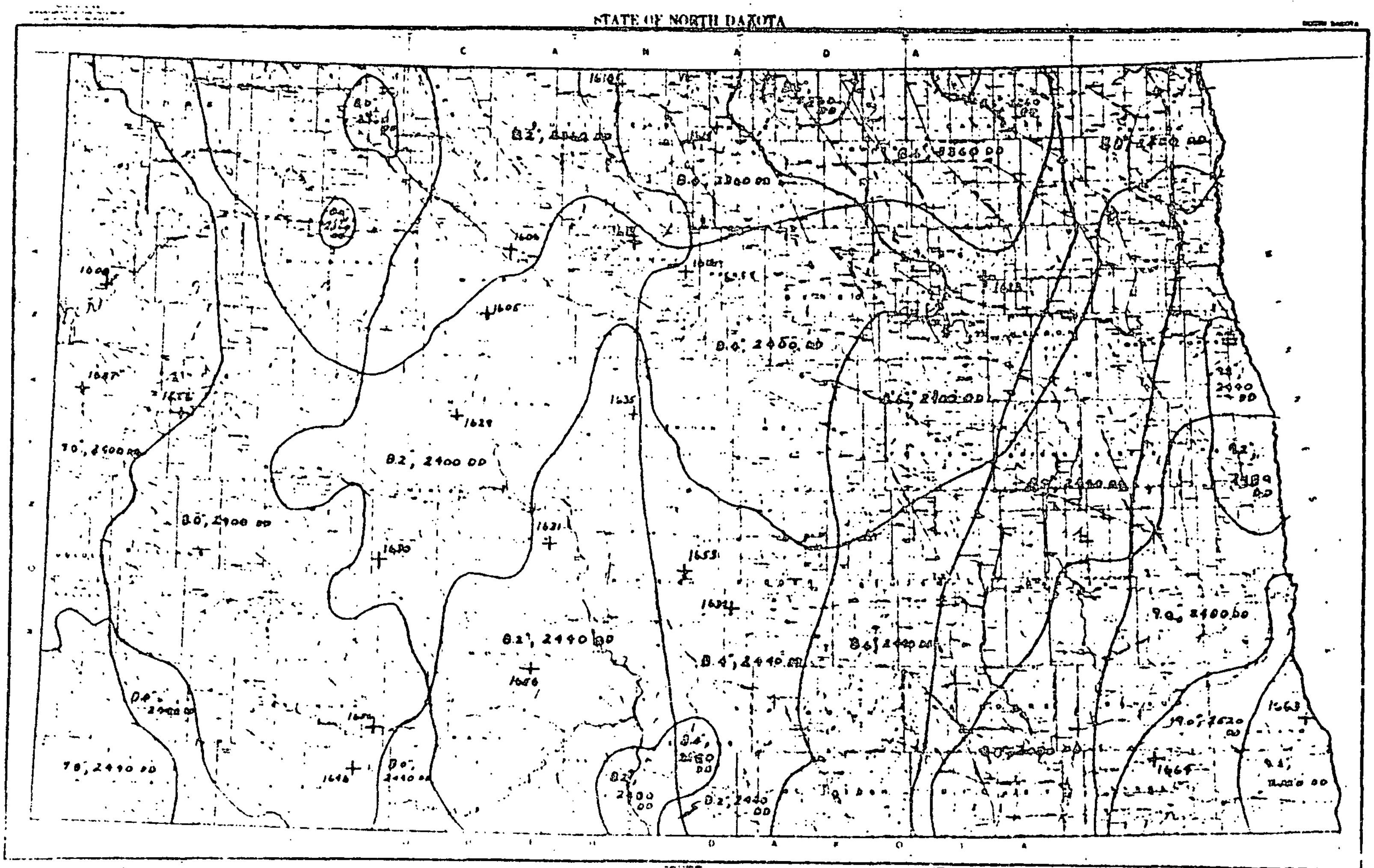

Figure 1.2 Climatic Strata for the State of North Dakota Utilized in the Grouping Analysis. The lower limits for long term average growing season precipitation (reported in inches) and degree-days are recorded in each stratum.

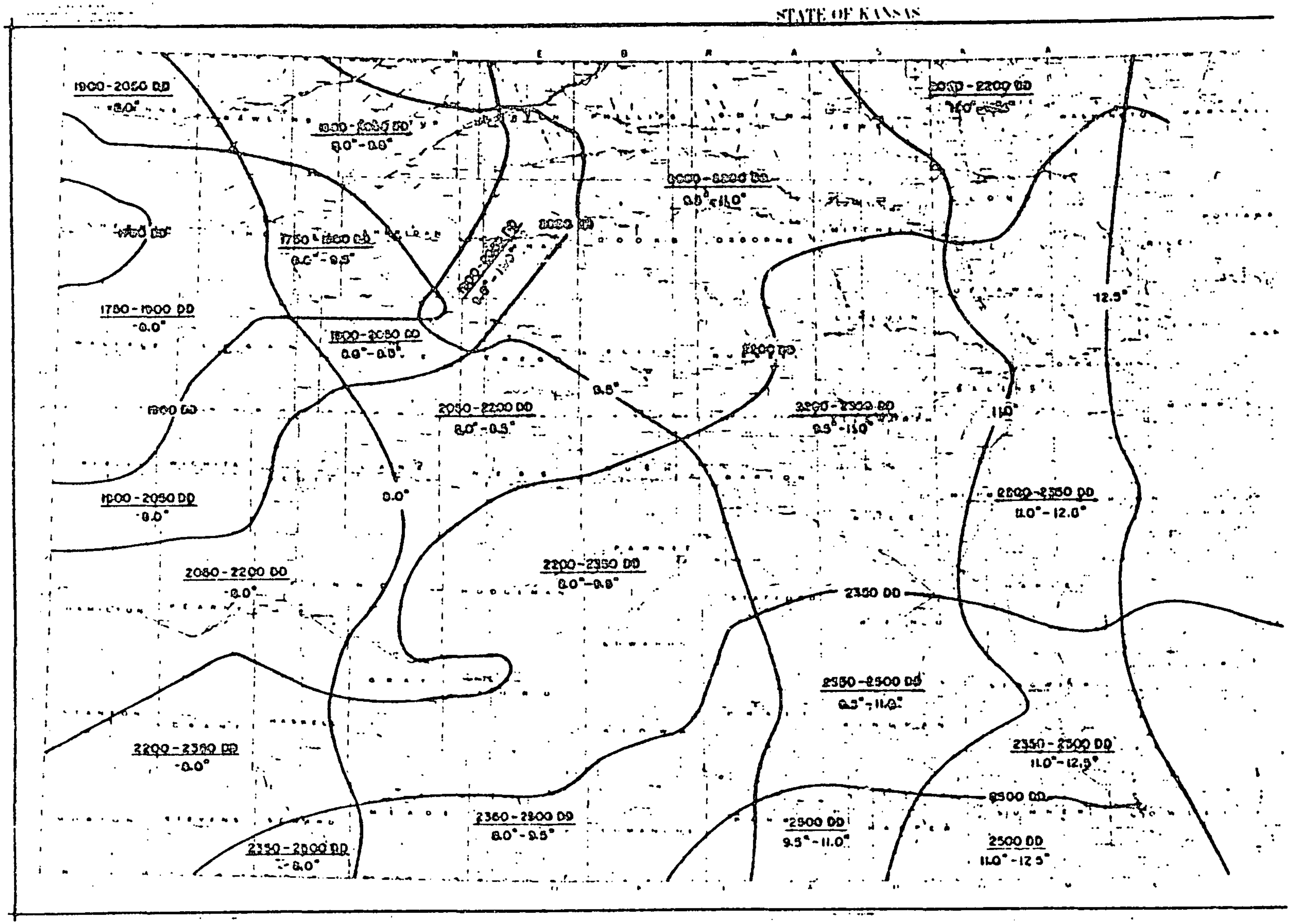

Figure 1.3 Climatic Strata for the State of Kansas Utilized in the Grouping Analysis. The ranges for long term average growing season precipitation (reported in inches) and degree-days are recorded in each stratum as denominator and numerator, respectively. When a range is not given, a range is assumed in the obvious plus or minus direction.

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1.4 RESULTS

SUBTASK A: STRATA GROUPING ANALYSIS

Within each state, all possible pairs of strata listed in Tables 1.2 and 1.3 were tested for spectral similarity. For each strata pair, Hotelling's T^2 test was applied separately to a sample of pixels from the 75-100% wheat cluster group (if this group was represented in both strata) and similarly to a sample of pixels from the 50-<75% wheat cluster group. Pixel data from both cluster groups in each stratum was also pooled and tested against corresponding pooled data in other strata.

Results presented in Table 1.4 for tests based on pooling cluster groups 1 and 2 (75-100% wheat and 50-<75% wheat, respectively) show that <u>within a given climatic stratum</u> the null hypothesis of spectral similarity between land use soil strata was accepted 32 to 75% of the time. Significance levels used for rejection were $\alpha \leq .05$ and $\alpha \leq .01$. The acceptance rate between adjacent climatic strata, i.e. strata differing by one class of either long term growing degree-days or precipitation (not both), ran between 0 and 43%. Results for tests across climatic strata diagonally adjacent (differing by one class in both degree-days and precipitation) available from North Dakota gave acceptance rates of 50% (date #1) and 67% (date #2) for either significance level. In general, low rates of acceptance prevailed for land use/soils strata pairs separated by more than one adjacent climatic stratum.

Based on these results three basic patterns were evident for the two states and two date sets involved:

(1) The wheat signature population generally overlapped within a given climatic stratum. This pattern was more pronounced on the later as opposed to the earlier date set.

(2) Wheat signature overlap also often occurred between horizontally, vertically or diagonally adjacent climatic strata. The frequency of overlap was generally at a lower rate than within a given climatic stratum. It should be noted that no diagonally adjacent climatic strata signature comparisons were available for Kansas. Given the somewhat larger areal extent of the climatic strata in Kansas relative to North Dakota (owing to the wider class values for degree-days and precipitation used in Kansas), the signature overlap rate between diagonally adjacent climatic strata in Kansas is expected to be lower than that obtained in North Dakota.

(3) Wheat signatures rarely overlapped beyond an adjacent climatic stratum.

Before interpreting these strata grouping analysis patterns the results of the spectral sensitivity analysis will be presented.

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Table 1.4: Hotelling's T^2 Test Results Obtained in the Strata Grouping Analysis When Pixels Sampled From Cluster Sets 1 and 2 (75-100% wheat and 50-<75%, respectively) Were Pooled Within Each Land Use/Soil Stratum

	Frequency With Which the Null Hypothesis of Spectral Similarity Was Accepted When All Pairs of Land Use/Soil Strata Included in Sample Where Considered		
	Within Same Climatic Stratum	Between Vertically or Horizontally Adjacent Climatic Strata	Between Diagonally Adjacent Climatic Strata
Kansas	32% (α<5%)*	19%	---***
Date Set #1	42% (α<1%)*	43%	---
Kansas	50%	0%**	---
Date Set #2	75%	0%**	---
North Dakota	33%	24%	50%
Date Set #1	50%	24%	50%
North Dakota	63%	---	67%
Date Set #2	75%	---	67%

*Level of significance for rejection of null hypothesis set at α<5% for top entry and α<1% for bottom entry.

**Based on only three possible strata matches available for test.

***No strata pairs available for test.

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SUBTASK B: SIGNATURE CONTROLLING FACTOR SENSITIVITY ANALYSIS

Pixel data from both the 75-100% wheat and 50-<100% wheat classes were pooled and regressed on corresponding static, season-specific, and Landsat pass-specific signature prediction variable data. Results for individual regression on each Landsat and Tasselled Cap (Kauth) band are presented in Tables 1.5 - 1.20. The Tables are arranged first by state, then by date set #1 or #2, next by Landsat versus Tasselled Cap bands, and finally by ordered regression versus regression without prior ordering.

The most striking feature of the tables, showing results for Landsat bands with ordered regression (Tables 1.5, 1.7, 1.13, 1.15) is the significant importance of long term growing season degree-days and/or precipitation in accounting for the variation in spectral response. In this case degree-days was the strongest on both Kansas date sets and the second North Dakota date set. Long term growing season ppt. accounted for the larger share of variance on the first North Dakota date set. The other variable accounting for substantial amounts of spectral variance was cultivated area percent. This variable, obtained from the static stratification land use code, was significant in Landsat Bands 6 and 7 on date set #2 in both states and in all bands on date set #1 in North Dakota. An evaluation of the cross variable correlation matrix suggests that the importance of the cultivated percent was largely an artifact of the sample distribution in North Dakota. One other variable, available soil water holding capacity (AWC), was expected to be significant in North Dakota. Unfortunately, AWC values could not be calculated for every land use/soil stratum and consequently this variable (as well as composite variables using AWC) was omitted from the sensitivity analysis.

At the bottom of the tables summarizing ordered regression results are three additional entries by band: Total R^2, $\sqrt{MSE}$, and Total Sum of Squares. The first of these entries is a sum of the R^2 accounted for by each predictor variable listed on the left. This sum is equal to the total explained variation in grey level values in each Landsat band. In Kansas total variation explained by predictor variables averaged 61% on date set #1 and 80% on date set #2. Similar figures for North Dakota were 54% and 27%. The lower figure on the second date in North Dakota appears to be due to the small size of sample and possibly also to a relatively flat wheat spectral response surface over North Dakota on that date. The square root of the mean square error ($\sqrt{MSE}$) represents the one standard error level for regression expressed in grey level counts by band. This value represents an interval on either side of the mean spectral response estimated from the sample in which the true mean spectral value (for wheat cluster groups 1 and 2 combined) should fall 68% of the time.* The smaller $\sqrt{MSE}$, the less

*Assuming the regression model is correct and the differences (residuals between true and predicted values are normally distributed about the regression lines.

TABLE 1.5.

KANSAS

SPECTRAL SENSITIVITY ANALYSIS ($\triangle$ R^2 VALUES)

ORDERED REGRESSION

DATE: 18, 19, 20 JANUARY 1976

NO. OF PIXELS SAMPLED: 454

		L4	L5	L6	L7
1.	CULTIVATED PCT.	.01		.02	
2.	WATER HOLDING CAPACITY	.01	.01	.01	.01
3.	L.T. GROW. SEASON DEG. - DAYS	.17	.19	.43	.35
4.	L.T. GROW. SEASON PRECIP.	.04	.09	.04	.06
5.	(24xAWC) x LTGS PRECIP.	.02	.03	.02	.04
6.	L.T. GROWING SEASON EVAP.	.01			.01
7.	(24xAWC) x LTGS EVAP.	.03	.03	.03	.04
8.	AVE. JAN. TEMP.	.04	.06	.07	.05
9.	PLANT. SEASON DEG. - DAYS				
10.	PLANT. SEASON PPT.	.02	.01	.01	.01
11.	SCAN ANGLE	.02	.01		
12.	7/5 RATIO	.10	.18	.02	.17
	TOTAL R^2	.46	.61	.54	.73
	$\sqrt{MSE}$	3.3	4.5	6.3	2.4
	TOTAL SUM OF SQUARES	8.9 K	22.9 K	49.5 K	9.0 K

Table 1.5

KANSAS

Spectral Sensitivity Analysis

Regression Without Prior Ordering (Order of Entry Listed)

Date: 18, 19, 20 January 1976

No. of Pixels Sampled: 454

		L4	L5	L6	L7
1.	Cultivated Pct.	4	4	8	7
2.	Water Holding Capacity		3		
3.	L.T. Grow. Season Deg-Days	5	5	6	6
4.	L.T. Grow. Season Precip.		11	5	4
5.	(24xAWC) x LTGS Precip.	3	10	9	
6.	L.T. Growing Season Evap.	8	7	3	2
7.	(24xAWC) x LTGS Evap.	6	6	10	8
8.	Ave. Jan. Temp.	7	8	4	3
9.	Plant. Season Deg. - Days	1(.24)	1(.28)	1(.51)	1(.43)
10.	Plant. Season Ppt.	2	2	2	5
11.	Scan Angle	9	9	7	9

TABLE 1.7

KANSAS

SPECTRAL SENSITIVITY ANALYSIS (ΔR^2 VALUES)

ORDERED REGRESSION

DATE: 4,6,7 MAY 1976

NO. OF PIXELS SAMPLED: 162

	L4	L5	L6	L7
1. CULTIVATED PCT.			.21	.36
2. WATER HOLDING CAPACITY (AWC)	.04	.05	.01	.03
3. L.T. GROW. SEASON DEG.-DAYS	.80	.78	.53	.30
4. L.T. GROW. SEASON PPT.	.02		.01	.04
5. (24xAWC) x LTGS PPT.	.01	.02	.01	.01
TOTAL R^2	.86	.84	.76	.74
$\sqrt{MSE}$	5.87	8.19	9.05	4.20
TOTAL SUM OF SQUARES	38.8 K	67.0 K	54.2 K	10.7 K

TABLE 1.8

KANSAS

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SPECTRAL SENSITIVITY ANALYSIS

<u>REGRESSION WITHOUT PRIOR ORDERING</u> (ORDER OF ENTRY LISTED)

DATE: 4,6,7 MAY 1976

NO. OF PIXELS SAMPLED: 162

		L4	L5	L6	L7
1.	CULTIVATED PCT.	2(.31)	2(.28)	5	6
2.	WATER HOLDING CAPACITY (AWC)				5
3.	L.T. GROW. SEASON DEG. - DAYS	1(.49)	1(.51)	1(.71)	1(.65)
4.	L.T. GROW. SEASON PPT.	6			
5.	(24xAWC) x LTGS PPT.	4	6	4	
6.	L.T. GROW. SEASON EVAP.	5			
7.	ROBERTSON BIONUMBER			6	2
8.	AVE. JAN. TEMP.		4		4
9.	GROW. SEASON DEG. - DAYS		5	2	
10.	SCAN ANGLE	3	3	3	3

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TABLE 1.9: KANSAS

SPECTRAL SENSITIVITY ANALYSIS (ΔR^2 VALUES)

ORDERED REGRESSION: TASSELLED CAP

DATE: 18, 19, 20 JANUARY 1976

NO. OF PIXELS SAMPLED: 454

		K1	K2	K3	K4
1.	CULTIVATED PCT.	.01	.01		.03
2.	WATER HOLDING CAPACITY	.01			
3.	L.T. GROWING SEASON DEG-DAYS	.37	.22		.04
4.	L.T. GROW. SEASON PPT.	.07		.02	.02
5.	(24xAWC) X LTSG PPT.	.03			.01
6.	L.T. GROW. SEASON EVAP.			.01	.03
7.	(24xAWC) X LTSG EVAP.	.04	.01		.01
8.	AVE. JAN TEMP.	.07	.01		
9.	PLANT. SEASON DEG-DAYS				
10.	PLANT. SEASON PPT.	.01			
11.	SCAN ANGLE			.01	
12.	7/5 RATIO		.59		.10
	TOTAL R^2	.61	.85	.05	.27
	$\sqrt{MSE}$	8.10	2.00	2.10	1.50
	TOTAL SUM OF SQUARES	74.8K	12.2K	2.0K	1.4K

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TABLE 1.10: KANSAS

SPECTRAL SENSITIVITY ANALYSIS

REGRESSION WITHOUT PRIOR ORDERING (ORDER OF ENTRY LISTED)

TASSELLED CAP

DATE: 18, 19, 20 JANUARY 1976

NO. OF PIXELS SAMPLED: 454

		K1	K2	K3	K4
1.	CULTIVATED PCT.	8	7	9	7
2.	L.T. GROW. SEASON DEG-DAYS	6	1(.21)	4	1(.06)
3.	L.T. GROW. SEASON PPT.	5	5	1(.01)	3
4.	(24xAWC)xLTGS PRECIP.	10	8	10	5
5.	L.T. GROW. SEASON EVAP.	3	3	2	2
6.	(24xAWC)xLTGS EVAP.	9	9	6	6
7.	AVE. JAN. TEMP.	4	4	5	10
8.	PLANT. SEASON DEG-DAYS	1(.47)		7	4
9.	PLANT. SEASON PPT.	2	2	3	8
10.	SCAN ANGLE	7	6	8	9

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TABLE 1.11: KANSAS

SPECTRAL SENSITIVITY ANALYSIS ($\Delta R2$ VALUES)

ORDERED REGRESSION; TASSELLED CAP

DATE: 4, 6, 7 MAY 1976

NO. OF PIXELS SAMPLED: 162

		K1	K2	K3	K4
1.	CULTIVATED PCT.	.07	.23	.01	.09
2.	WATER HOLDING CAPACITY (AWC)		.20	.03	.01
3.	L.T. GROW. SEASON DEG-DAYS	.75	.26	.61	
4.	L.T. GROW. SEASON PPT.		.03	.13	.17
5.	(24xAWC)xLTGS PPT.	.01			
	TOTAL R^2	.84	.73	.78	.27
	$\sqrt{MSE}$	12.2	6.5	2.4	2.0
TOTAL SUM OF SQUARES		141.2K	24.7K	.6K	.8K

TABLE 1.12: KANSAS

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SPECTRAL SENSITIVITY ANALYSIS

REGRESSION WITHOUT PRIOR ORDERING (ORDER OF ENTRY LISTED)

TASSELLED CAP

DATE: 4, 6, 7 MAY 1976

NO. OF PIXELS SAMPLED: 162

		K1	K2	K3	K4
1.	CULTIVATED PCT.	2(.13)	6	5	4
2.	WATER HOLDING CAPACITY (AWC)		1(.43)	2(.44)	
3.	L.T. GROW SEASON DEG-DAYS	1(.69)			2
4.	(24xAWC)xLTGS PPT.				1(.14)
5.	L.T. GROW SEASON EVAP.				3
6.	ROBERTSON BIONUMBER	5	5	6	
7.	GROW SEASON DEG-DAYS			3	
8.	GROW SEASON PPT.	6		1(.34)	
9.	(24xAWCxGSP) - GSET		2(.29)		
10.	AVE JAN TEMP		3		
11.	PLANT SEASON DEG-DAYS	4			5
12.	PLANT SEASON PRECIP		4		
13.	SCAN ANGLE	3		4	

TABLE 1.13

NORTH DAKOTA

SPECTRAL SENSITIVITY ANALYSIS (Δ R^2 VALUES)

ORDERED REGRESSION

DATE: 24, 25, 28, 27, 28 MAY 1976
NO. OF PIXELS SAMPLED: 192

	L4	L5	L6	L7
1. CULTIVATED PCT	.27	.29	.23	.17
2. L.T. GROW. SEASON DEG-DAYS	.02	.02	.01	.04
3. L.T. GROW. SEASON PPT.	.31	.35	.13	.06
4. L.T. GROW. SEASON EVAP.	.02	.01	.03	.02
5. ROBERTSON BIONUMBER	.01	.01	.01	.01
6. GROW. SEASON DEG-DAYS	.01	.01		
7. GROW. SEASON PPT.	.02	.01	.02	.03
8. SUM. GROW. SEASON EVAP.			.03	.04
9. AVE. JAN. TEMP.				
TOTAL R^2	.61	.70	.46	.37
$\sqrt{MSE}$	3.7	5.0	7.5	3.7
TOTAL SUM OF SQUARES	6.3K	15.5K	18.7K	3.8K

TABLE 1.14

NORTH DAKOTA

SPECTRAL SENSITIVITY ANALYSIS

REGRESSION WITHOUT PRIOR ORDERING (ORDER OF ENTRY LISTED)

DATE: 24, 25, 26, 27, 28 MAY 1976
NO. OF PIXELS SAMPLED: 192

	L4	L5	L6	L7
1. CULTIVATED PCT	4	7	8	8
2. L.T. GROW. SEASON DEG-DAYS	5	4	3	3
3. L.T. GROW. SEASON PPT.	8		5	5
4. ROBERTSON BIONUMBER		3		
5. GROW. SEASON DEG-DAYS	6	5		
6. GROW. SEASON PPT.	3		6	6
7. SUM GROW. SEASON EVAP.	7	8		
8. AVE. JAN TEMP.			4	4
9. PLANT. SEASON DEG-DAYS				
10. PLANT. SEASON PPT.		6	7	7
11. FOUR DAY PPT.	1(.57)	1(.68)	1(.36)	1(.20)
12. SCAN ANGLE	2	2	2	2

TABLE 1.15

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NORTH DAKOTA

SPECTRAL SENSITIVITY ANALYSIS (Δ R^2 VALUES)

ORDERED REGRESSION

DATE: 30 JUNE; 1, 2 JULY 1976

NO. OF PIXELS SAMPLED: 157

	L4	L5	L6	L7
1. CULTIVATED PCT.	.04	.03	.10	.10
2. L.T. GROW. SEASON DEG-DAYS	.02		.22	.16
3. L.T. GROW. SEASON PPT.	.02	.01		.01
4. L.T. GROW. SEASON EVAP.	.07	.07	.03	.06
5. ROBERTSON BIONUMBER	.01	.03	.05	.07
TOTAL R^2	.15	.13	.40	.40
$\sqrt{MSE}$	2.2	2.8	6.7	3.9
TOTAL SUM OF SQUARES	.8K	1.4K	11.1K	3.9K

TABLE 1.16

NORTH DAKOTA

SPECTRAL SENSITIVITY ANALYSIS

REGRESSION WITHOUT PRIOR ORDERING (ORDER OF ENTRY LISTED)

DATE: 30 JUNE; 1, 2 JULY 1976
NO. OF PIXELS SAMPLED: 157

	L4	L5	L6	L7
1. CULTIVATED PCT.	4	4	4	4
2. L.T. GROW. SEASON DEG-DAYS	5			
3. L.T. GROW. SEASON PPT.		3(.11)	5	
4. L.T. GROW. SEASON EVAP.				5
5. GROW. SEASON DEG-DAYS	3(.13)			
6. GROW. SEASON PPT.			3(.13)	3(.09)
7. 4 DAY PPT.	1	1	1(.13)	1(.07)
8. SCAN ANGLE	2	2	2(.12)	2(.12)

TABLE 1.17: NORTH DAKOTA

SPECTRAL SENSITIVITY ANALYSIS (ΔR^2 VALUES)

ORDERED REGRESSION; TASSELLED CAP

DATE: 24, 25, 26, 27, 28 MAY 1976

NO. OF PIXELS SAMPLED: 192

	K1	K2	K3	K4
1. CULTIVATED PCT	.30	.01		
2. L.T. GROW SEASON DEG-DAYS		.11	.01	.03
3. L.T. GROW SEASON PPT	.26	.10	.04	
4. L.T. GROW SEASON EVAP	.02		.02	.02
5. ROBERTSON BIONUMBER	.01		.01	.01
6. GROW SEASON DEG-DAYS		.01	.01	.01
7. GROW SEASON PPT	.02		.01	.01
8. SUM GROW SEASON EVAP	.01	.03		.01
TOTAL R^2	.63	.26	.11	.09
$\sqrt{MSE}$	8.6	5.5	1.7	.9
TOTAL SUM OF SQUARES	36.2K	7.5K	.6K	.2K

TABLE 1.18: NORTH DAKOTA

SPECTRAL SENSITIVITY ANALYSIS

REGRESSION WITHOUT PRIOR ORDERING (ORDER OF ENTRY LISTED)

TASSELLED CAP

DATE: 24, 25, 26, 27, 28 MAY 1976

NO. OF PIXELS SAMPLED: 192

	K1	K2	K3	K4
1. CULTIVATED PCT.	7	6	3	
2. L.T. GROW SEASON DEG-DAYS	3	8	6	
3. L.T. GROW SEASON PPT		3		3(.06)
4. ROBERTSON BIONUMBER			7	
5. GROW SEASON DEG-DAYS		7	4	
6. GROW SEASON PPT	6		5	6
7. GROW SEASON EVAP	8			
8. AVE JAN TEMP	4	4		4
9. PLANT SEASON DEG-DAYS		5		
10. PLANT SEASON PPT	5			5
11. FOUR DAY PPT	1(.58)	1(.09)	1(.05)	1
12. SCAN ANGLE	2	2(.04)	2	2

TABLE 1.19: NORTH DAKOTA

SPECTRAL SENSITIVITY ANALYSIS (ΔR^2 VALUES)

ORDERED REGRESSION; TASSELLED CAP

DATE: 30 JUNE; 1, 2 JULY 1976

NO. OF PIXELS SAMPLED: 157

	K1	K2	K3	K4
1. CULTIVATED PCT	.07	.11	.06	.01
2. L.T. GROW SEASON DEG-DAYS	.23	.15		
3. L.T. GROW SEASON PPT		.01	.02	.05
4. L.T. GROW SEASON EVAP	.01	.06	.04	.10
5. ROBERTSON BIONUMBER	.03	.06		.04
TOTAL R^2	.34	.39	.13	.20
$\sqrt{MSE}$	5.5	6.3	1.2	1.2
TOTAL SUM OF SQUARES	7.0K	9.7K	.3K	.3K

TABLE 1.20: NORTH DAKOTA

SPECTRAL SENSITIVITY ANALYSIS

REGRESSION WITHOUT PRIOR ORDERING (ORDER OF ENTRY LISTED)

TASSELLED CAP

DATE: 30 JUNE; 1, 2 JULY 1976

NO. OF PIXELS SAMPLED: 157

	K1	K2	K3	K4
1. CULTIVATED PCT	4	4	4	4
2. L.T. GROW SEASON DEG-DAYS	5			5
3. L.T. GROW SEASON PPT				3(.17)
4. L.T. GROW SEASON EVAP		5	5	
5. GROW SEASON DEG-DAYS			3(.12)	
6. GROW SEASON PRECIP		3(.18)		
7. PLANT SEASON PRECIP	3(.09)			
8. FOUR DAY PRECIP	1(.14)	1(.08)	1	1
9. SCAN ANGLE	2(.11)	2(.11)	2	2

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error expected in predicting the mean band value from the signature predictor variables. The Total Sum of Squares entry is defined as the sum of the squared differences between a reflectance value for an individual pixel and the average reflectance value over all pixels in that band. Note that approximate variance by band is given when the total sums of squares is divided by the total number of pixels sampled per date. Care should be taken in comparing band variance between dates in that the same distribution of climatic strata could not be sampled on each date.

Results of regression without prior ordering of predictor variable entry into the equations fo Landsat bands are presented in Tables 1.6, 1.8, 1.14, and 1.16. While the reader is cautioned against putting much weight on the exact order of entry (See Appendix B), the following observations were deemed significant. In Kansas, variables entering first on date set #1 were fall 1975 planting season precipitation and degree-days. This was expected for a January 1976 pass-date. Long term growing season degree-days, cultivated percent, and scan angle were the first variables entered (i.e. having the highest correlation or partial correlation with the Landsat band values) into the regressions on the second date set in Kansas. Precipitation in the four days preceding Landsat pass (four day ppt.) and scan angle were entered consistently as the first and second variables on both dates in North Dakota. If present, four day ppt. can have an important impact on spectral signatures by wetting the soil or canopy surfaces. Other variables entering subsequently included either long term or season-specific degree-day or precipitation variables.

Review of the ordered regression results for the Tasselled Cap (Kauth) bands (Tables 1.9, 1.11, 1.17, 1.19) shows the long term growing season degree-day variable to be dominant in accounting for spectral variance on both Kansas dates and the second North Dakota date. This pattern was particularly evident in Bands 1 and 2 (brightness and greeness, respectively). The long term growing season degree-days term was also important on Band 2 of date set #1 in North Dakota, but the long term precipitation variable had greater overall significance on this date. Land use (cultivated area percent) and soil water holding capacity were found significant in the green band on the second date set in Kansas. As indicators of cropping intensity and capacity to supply moisture for growth, land use and AWC can be logically linked to the crop development thought to be measured by the greeness band. The relative importance shown for land use in Band 1 on the first North Dakota date set should be treated with caution. While moderate correlation between land use and soil brightness (Band 1) should be expected, examination of the data indicates that the high percent of spectral variability accounted for by land use may, in this case, be largely an artifact of the spatial distribution of samples.

Kauth band tables 1.10, 1.12, 1.18 and 1.20 show that the pattern of signature predictor variable entry when using regression without prior variable ordering follows closely that obtained for the Landsat bands in each

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state on each date set. Looking at all dates as a whole, the first variables entered into the regressions were usually some combination of scan angle, precipitation in the four days preceding Landsat pass, or long term and/or season-specific degree-day and precipitation terms.

To gain another viewpoint on the inherent structure or independent dimensions in the signature predictor variable set, a factor analysis was applied to the pixel sample data (Landsat reflectances) obtained from cluster groups 1 and 2. The procedure was to first perform a principal components rotation on the pixel sample for each date in each state. At this point, the location of each variable was expressed in terms of an orthogonal coordinate system (each axis being perpendicular or normal to every other). The first axis of this system has the greatest variation over all variables, the second axis the second most variation, etc. Next a vari-max orthogonal rotation technique was applied to the principal components results in order to get each signature predictor variable to load on one dimension (or "factor") as much as possible.

Approximately the same pattern of factor loading resulted in both Kansas and North Dakota. Namely, the first factor represented a water stress axis--positive values representing water loss (evaporation variables) and negative values water input (precipitation variables, soil water holding capacity). Axis #2 related to long term degree-days; Axis #3 to land use, and Axis #4 to scan angle. In North Dakota, season-specific precipitation joined long term degree-days on Axis #2 and season-specific temperature variables joined land use on Axis #3. This analysis largely confirmed and clarified the patterns in the sensitivity analysis.

1.5 CONCLUSIONS RELATIVE TO STRATA GROUPING FOR SIGNATURE EXTENSION

Using the results of the spectral sensitivity analysis as an aid, we offer the following interpretation of results gained in the strata grouping analysis:

(1) The spectral surface appears to be relatively smooth, gradually changing over space. The spectral overlap encountered within and between climatic strata support this notion.

(2) Furthermore, the results of the sensitivity analysis indicate that this surface is strongly tied to degree-day and precipitation-crop development variables. The spectral influences of long term growing season degree-days and at times long term growing season precipitation were found to be particularly significant. These, of course, were also the two variables used to define the climatic strata.

(3) The sensitivity analysis also suggests that exceptions to (1) may be largely due to pass-specific precipitation differences, their interaction with soil type reflectances, and scan angle differences. Land use may also have an impact in situations

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where it is strongly correlated with soil type or with particular agricultural practices affecting plant canopy reflectance (e.g. irrigation, field size and shape).

1.6 *IMPLICATIONS OF RESULTS RELATIVE TO THE GENERAL PROBLEM OF SIGNATURE EXTENSION*

(1) Multisegment clustering and classification should be possible using climatic strata, or more generally, distance on a climate-related spectral surface, as a guide to segment grouping. In other words, it should be possible to use spectral training data (cover type-specific Landsat band means, variances, and covariances) obtained from a specially selected sample of LACIE segments to classify with acceptable accuracy the entire set of LACIE segments falling within climatic partitions (e.g. see discussion by Kauth et al. 1977). A cost savings over training and classifying each segment separately should result.

(2) To achieve successful multisegment classification described in (1) will, in all probability, require sun angle and haze correction to a common standard (e.g. XSTAR as used in this study).

(3) Extension of training segment signatures beyond adjacent climatic strata will require some form of signature transformation.

(4) While pass-specific precipitation, soil reflectance and scan angle may generate spectral outliers, these should not in general pose significant problems to multisegment clustering within climatic strata. This is not to say, however, that recognition segments (segments into which signature is extended from others) having no adequate spectral analogues will not occur. Undoubtedly they will. But within many biostages or combinations of biostages, multisegment classification as described in (1) should be possible with at least some portion of the population of sample segments at hand. Further technical developments in scan angle correction and flagging of soil type conditions, etc., in which outliers will occur should serve to maximize successful use of the multisegment approach to signature extension within climatic strata.

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Section 2.0

Task II: The Development of Multitemporal Interpretation Procedures

by

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2.0 TASK II: THE DEVELOPMENT OF MULTITEMPORAL INTERPRETATION PROCEDURES

2.1.0 INTRODUCTION

Before proceeding with documentation of analysis procedures and data products developed within this task for LACIE, it is fitting to review the status of current interpretation procedures and data presentation formats being utilized by the analysts. Specifically, it is appropriate to examine 1) the characteristics of Landsat multispectral-temporal data, and 2) the analysis procedures being applied to these data.

2.1.1 Perspective on Landsat Data

The Landsat spectral-temporal data is significantly different from traditional, conventional photographic data that analysts have worked with in the past. Landsat data differs significantly from conventional photographic data in scale, resolution, and areal coverage within a single frame. Even more significant differences are band width of the sensors, number of sensors, the repetitiveness of the acquisitions, and the digital format of the data.

The differences between Landsat data and conventional photographic imagery are often not made sufficiently clear when instructing analysts. Interpretation procedures for Landsat data, are often presented from the same perspective, and expressed in the same terminology (concepts) as used in conventional photointerpretation. While the concepts of traditional image interpretation still have relevance to the interpretation of any image formated data, these principles and concepts need to be modified and restated within the context of the Landsat situation. Furthermore, Landsat provides additional information to the analyst that photographic data does not. This additional information comes from the <u>digital</u> spectral-temporal response data of the relatively narrow band (compared to photographic data) multispectral sensors. Therefore, the analyst must no longer be considered merely an image analyst, but one capable of efficiently integrating information from both digital and image formats. Numeric digital data and image formated data contribute significantly different information to the analyst. The development of new interpretation procedures for use of Landsat data, then, must take into account the full potentials of Landsat data and not concentrate solely or primarily on interpretation of image formated data.

2.1.2 The Analysis Process

It is also important to understand the components of the analysis (interpretation) process itself (called labeling in LACIE). In simple terms, the interpretation process consists of three main components: 1) feature detection, 2) feature identification, and 3) feature condition assessment. While all three processes may occur simultaneously and iteratively, they can be treated separately for the purpose of simplicity and understanding. Feature detection can be defined as the action of discriminating a unique feature based on spectral, spacial, and temporal characteristics observable within

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Landsat multitemporal-spectral data. Feature identification can be defined as the action of assigning a name (e.g. wheat, non-wheat) to the detected feature. Feature condition assessment can be defined as the action of ascribing some quality of state (e.g. late developing, poor stand, harvested) to the feature. Correct feature identification can not properly proceed unless feature detection has first occurred. Feature detection,however, does not insure feature identification. Errors in labeling can thus occur due to (1) failure to detect a feature of interest, and (2) failure to correctly identify a detected feature.

Feature Detection

Within LACIE, the features that an analyst wishes to detect are cropped fields. The characteristics which alert an analyst to the presence of a cropped field are: 1) the existence of an area enclosed within a man-made (or man-modified) boundary (a spacial characteristic e.g., the enclosing boundary is often rectilinear in nature, or can follow topographic elevational contours or other topographic feature directional trends; 2) the development of a vegetation canopy within the growing season for a given region (temporal-spectral characteristic); and, 3) the quality of presence or condition of the vegetation canopy within specific time periods related to given crop type biostages (spectral-temporal characteristic). Of these three characteristics, the second is the most important to the analyst for the detection and identification of wheat or any other crop. Determination of the other two characteristics is necessary when significant overlap exists between wheat and confusion conditions, or when acquisitions are missing or of poor quality. Obviously, the probability of correctly identifying a crop within a given field will be low if its vegetation canopy cannot be detected during a critical vegetation biophase. If the standard CIR image product (Product 1) fails to represent a vegetation canopy in a noramlly expected manner, mislabeling may occur as the result of analyst's failure to detect the presence of vegetation within a critical biophase. Product 1 tends to inadequately represent low density vegetation canopies. Many, though not all, of these low canopy situations are detectable upon examination of the actual Landsat digital data or transformations of the Landsat digital data (vegetation indicators such as MSS7/MSS5 ratio or Tassel Cap green numbers). Thus auxiliary products (analyst aids) which present Landsat digital or transformed digital data directly to the analyst, could aid in increasing labeling accuracies where errors could occur due to non-detection of low density canopies on spectrally distorted image products.

Digital spectral data gives the analyst a quantitative measure of canopy development or condition. The image products do not allow for easy quantified comparative measurement. The ability to make quantified comparative measurements of canopy development may be useful in discriminating wheat from close confusion crops. Thus digital spectral data products are meant to provide the analyst with a more precise measure of condition, and allow him to calibrate the image products with which he is working. Lest the forgoing discussion place in doubt the utility of image products, let it be clearly recognized that image products are vital for extraction of spacial and spectral textural information necessary for feature identification.

Feature Identification

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While standard image and auxiliary aid products allow an analyst to detect a feature, ancillary data and a priori knowledge from outside a specific set of Landsat data are necessary for the analyst to identify and label a detected feature. To identify a feature an analyst develops correlations between given spectral-temporal response patterns, the ancillary data concerning local and/or regional ground conditions and a priori knowledge.

By analyzing these data the analyst then determines the probable identity of a given point. An analyst's ability to perform this analysis is dependent upon his past experience, his familiarity with the given environment, the quality of instruction received, the quality of the guidelines available to him which relate spectral responses to ground conditions, and the development of his analytical thought processes.

At present, analysts have very little information about the correlation between Landsat spectral response and ground conditions, because Landsat data has not been available for a period sufficient to develop these relationships. The analyst, therefore, must develop these correlations (or more appropriately inferences to possible correlations) for himself from the ancillary data and spectral data given to him. Until the necessary correlations can be definitively determined for presentation to the analyst, the identification process will continue to be heavily dependent on the skills and experience of the individual analyst.

Ancillary data currently considered most necessary to the analyst are listed in Table 2.'. These data should consist of mean values and descriptions of average, normal conditions, as well as year-to-year and spacial variability. Much ancillary data is deficient in variability information.

2.2.0 OVERALL TASK OBJECTIVE

The overall goal of this task was to develop analysis procedures and data products that would allow the analyst to take maximum advantage of the information contained within Landsat data. In spite of current limited spectral response to ground condition correlations, it was felt that procedures based on current general guidelines could be developed now and later refined as the results from data correlation studies become available. Specifically, the Task II objective was to develop interpretation methods and guidelines for utilizing multispectral Landsat data which were improvements to the current LACIE methods. This involved 1) the development and testing of decision criteria for the identification and estimation of small grains and wheat from Landsat data, and 2) the development and testing of multitemporal data presentation formats. To efficiently pursue the objective Task II was approached through three subtasks. These subtasks were 1) Subtask A - FAMILIARIZATION WITH JSC/LACIE PHOTOINTERPRETATION PROCEDURES, 2) Subtask B - DEVELOPMENT OF MULTITEMPORAL INTERPRETATION PROCEDURES whereby individual temporal images and spectral data are analyzed by means of a decision logic for the identification of small grains and wheat, and 3) Subtask C - EXPLORATION AND EVALUATION OF METHODS FOR REDUCING THE DEMENSIONALITY OF MULTITEMPORAL DATA to a single image of multitemporally combined data and/or a numeric representation of the spectral data.

TABLE 2.1: ANCILLARY DATA MOST NECESSARY FOR FEATURE IDENTIFICATION

- *DATA FOR ALL MAJOR CROPS WITHIN A REGION*
  - *CROP CALENDARS*
  - *CROP HISTORICAL PROPORTIONS*
  - *CROPPING PRACTICES*
- *METEOROLOGICAL DATA AFFECTING CROP DEVELOPMENT AND/OR SPECTRAL RESPONSE OF CROP*
  - *RECENT PRECIPITATION*
  - *POTENTIAL YIELD (Integrator of all climatic, adaphic, and pathogenic parameters)*
  - *EPISODAL EVENTS DATA*
- *SPECTRAL RESPONSE CORRELATED TO CROP DEVELOPMENT STAGES*

2.3.0 SUBTASK A: FAMILIARIZATION WITH JSC/LACIE PHOTOINTERPRETATION PROCEDURES

2.3.1 OBJECTIVE

The specific objective of this subtask was for UCB personnel to become familiar with LACIE interpretation procedures and to remain current on all implemented, and proposed interpretation procedural modifications. This subtask was vital to efficient and effective performance upon the other subtasks within Task II.

2.3.2 SUMMARY AND DISCUSSION

An initial tutorial session and over-the-shoulder interpretation session on the "old" Fields Procedure was presented to UCB personnel by CAMS Operational personnel in August 1976. Sessions with CAMS personnel in March 1977 and July 1977 provided updates on the Small Fields Procedure and Procedure 1. These updates coincided with UCB's participation in the development of LIST and an evaluation of the "South Dakota Overestimation Problem".

2.3.2.1 Participation in LIST

LIST (Label Identification from Statistical Tabulation) was a procedure conceived within NASA/JSC, and cooperatively developed by personnel from Lockheed Electronics, ERIM and UCB. LIST is "basically a statistical approch for estimating dot labels from analyst responses to a list of questions, and from associated ancillary data."[1] The motivation behind LIST was to develop a dot labeling procedure that would standardize the labeling process, and, hopefully, decrease variability, and increase accuracy of dot labels for wheat. UCB's participation in LIST was mainly confined to aiding in the development of the list of questions to be answered by the analysts from Landsat and ancillary data.

The basic LIST questions paralleled the analysis approach used by analysts, and were structured as follows:

A. Total Segment and/or Partition level Questions
   1. Data input questions
   2. Data output from evaluation analysis questions

B. Dot Specific Questions
   1. Data input questions
   2. Data output from evaluation analysis questions

Total segment and/or partition level questions were relevant to the analysis of all the dots within a segment. Thus, data had to be extracted and evaluated only once, though it applied to every dot specific analysis. Dot specific questions, however, had to be answered each time the analyst moved to a new dot (in Procedure 1 system). The answers to these questions varied, and were totally dependent on the specific situation of each independent dot.

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[1] NASA, March 7, 1977 Plan for Defining Dot Labeling Procedures for Procedure 1 - the LIST Method.

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Data input questions were information gathering questions, and no evaluation analysis was required. Information was extracted and recorded as a reported fact from ancillary data. Data output from evaluation analysis questions required that the analyst evaluate the input data and make some judgment before the question could be answered. An outline of the logic structure for these questions is shown in Table 2.2. The initial set of questions have since been modificed and streamlined by NASA/JSC and LEC personnel and some initial testing has occurred. UCB, however, has not been involved in these later developments.

Relevant to the goals of subtask A, however, participation in the development of LIST provided UCB with an excellent opportunity to establish contacts with LACIE operational analysts, and to develop a better appreciation of the analysts' interpretation problems. There was also the opportunity to become familiar with the new analyst aids - namely the Tasseled Cap greeness-brightness trajectory plots and the spectral scattergram plots.

In regard to the trajectory plots of greeness vs. brightness, it was felt that these plots would be more meaningful to the analyst if the temporal co-ordinate was more directly incorporated into the plots. That is, greeness and brightness could be plotted individually against a temporal axis, and a ratio of brightness to greeness could be plotted against time thus incorporating all three paramaters (greeness, brightness, and time) within one plot. In that the temporal characteristic of plant development are the most significant for crop identification, any subset of spectral aids must strive to represent Landsat vegetation development indicators vs. time in a clear and straightforward manner.

2.3.2.2 PFC Product Evaluation

During this last year's effort, UCB was also involved in a special PFC Alternative Product evaluation. Participation in that effort allowed UCB the opportunity to evaluate and work with the new "Kraus" Product which is now being made available in JSC analyst packets. Results of the UCB study on PFC projects were reported upon in Hay, etc., 1977a. Relative to the objective of this subtask, the PFC study helped develop increased awareness for the role that image mapping functions can play in the presentation of image data to an analyst.

2.3.2.3 "South Dakota Overesimation Problem"

Another task that UCB was requested to participate in this last year was an evaluation of the "South Dakota winter wheat measurement problem." While the conclusions drawn by UCB concerning the "problem" were in the main supportive of the general conclusions drawn by an in-house JSC team, this task provided an opportunity for UCB to get an updated briefing on Procedure 1 as implemented. The results of the "South Dakota" study, as reprinted from an earlier report, are given in Appendix C.

Table 2.2 LOGIC STRUCTURE OF ORIGINAL LIST QUESTIONS

A. Total Segment and/or Partition Level Questions

1. Data input questions

   a. Location of segment
   b. Agro-Met data

      1) Climatic
      2) Cropping Practice

2. Data output from evaluation analysis

   a. Evaluate relevance of input data to actual segment from full frame Landsat analysis

B. Dot Specific Questions

1. Data input questions

   a. Pixel quality questions (misregistered, etc.)
   b. Spectral data for pixel (e.g. color on image, green number, etc.)

2. Data output from evaluation analysis

   a. Evaluate input data and determine if pixel follows expectations for small grains and/or wheat

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2.4.0 SUBTASK B: DEVELOPMENT OF MULTITEMPORAL INTERPRETATION PROCEDURES

2.4.1 OBJECTIVE

The objective of this subtask was to develop and explore new and improved multitemporal interpretation procedures that would increase AI labeling accuracy or efficiency relative to current LACIE interpretation procedures. Specifically, procedures that integrate the interpretation of standard multitemporal Landsat image-formatted data and preprocessed spectral, numeric- or graphically-formatted data were explored. An emphasis was placed on the development of procedures that could be standardized as much as possible within the operation, production oriented context of LACIE. This was desirable in that the effects of analyst performance variability could be minimized in the measurement porcedures for acreage estimation.

2.4.2 APPROACH

Procedure modifications explored within this contract period made use of Landsat vegetation indicators such as 2x MSS 7/MSS 5 ratio, and Tasselled Cap green and brightness numbers. It was felt that direct manual analysis of the temporal pattern of the 2x MSS 7/MSS 5 ratio, green numbers, and brightness numbers for fields, coupled with analysis guidelines concerning vegetation detection using these measure could possibly be utilized to enhance small grains and/or wheat detection and/or identification. After reviewing the current state of knowledge concerning these vegetation indicators, procedures and guidelines were developed for effective utilization of these indeces in the interpretation of Landsat data.

Another aspect of labelling and acreage estimation explored in this subtask was that of stratification and sampling within the segment. The development of procedures for better data interpretation and more efficient sampling were pursued in recognition of, and agreement with, the philosophy behind the developing Procedure 1.

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2.4.2.1 Development of the Delta Function Stratification (DFS) Procedure

Unlabelled Cluster Display Procedure - Unitemporal Mode

After reviewing the JSC Fields Procedure at the outset of this task, it was apparent that analyst definition of spectral subclasses based on interpretation of PFC imagery alone was inefficient and inaccurate. It was felt that clustering information should be made available to the analyst to aid him in training statistics definition.

Most of the initial displays of unlabelled cluster data employ a random assignment of colors to the various clusters. This random color assignment does not facilitate rapid interpetation, and correlation of the cluster data with raw Landsat imagery. A desireable color display scheme would allow for the visual grouping of related clusters so that landscape features are clearly identifiable, and comparison of cluster maps with Landsat raw data imagery (or ground data) is facilitated. This can be accomplished by assigning analogous (adjacent) colors to similar clusters that belong to the same general class but represent different spectral subclasses within that class. The display of related clusters in analogous colors will allow visual grouping of related clusters and preservation of landscape features. The AI can more readily see relationships within the data, and thus deliver a better final analysis of that data.

An easy and relatively reliable method for ordering and associating unlabelled clusters was needed. In previous experience with the 2x MSS 7/MSS 5 ratio, relatively good temporal correlation with vegetation development (canopy development) was observed. Therefore, it was decided to use the 2x MSS 7/MSS 5 ratio as an indexing number for ordering and associating unlabelled clusters. The procedure is as follows:

1) The data is clustered using the following procedure:

   a) Five 20 point by 20 line seed areas distributed throughout the segment* are clustered** for 10 iterations using a STDMAX = 4.0, MAXCLS = 50, and NMIN = 30.

   b) Punched output statistics from the seed run are input into a second clustoirng run on the full segment for an additional 10 iterations at a STDMAX = 4.0, MAXCLS = 60, and NMIN = 30. This equates to a total of 20 iterations for the segment.

   c) Punched output statistics and a display map on tape are acquired from the second clustering run.

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*The upper left corner of the five 20 point by 20 line seed areas are: a) 1,1; b) 1,97; c) 88,48; d) 176,1; e) 176,97.

**Clustering algorithm ISOCLAS - UCB's adaptation of JSC ISOCLS.

2) The stat deck from the second clustering run is input to a program called CLODER. CLODER computes the 2x MSS 7/MSS 5 means ratio for each cluster.

3) Clusters are ordered, from highest to lowest, by the 2x MSS 7/MSS 5 ratio of the cluster means.

4) The ordered clusters are assigned colors from a spectrally ordered sequence of colors beginning with the warmest colors (red-violet) and proceeding to the coolest colors (blue-violet). Figure 2.1 is an example of a unitemporal unlabelled ordered cluster map.

Extention of Unlabelled Cluster Display Procedure to Multitemporal Data

The next step in the development of DFS was the extension of the unitemporal Unlabelled Cluster Display Procedure to the multitemporal situation. The two major problems associated with this next step were 1) the proper ordering and associating of the clusters from multitemporal space, and 2) finding enough adequately distinguishable, spectrally ordered sequential colors to assign to the large number of clusters developed in multitemporal space, viz., approaching 60 clusters versus less than 25 clusters in unitemporal space.

Since small grains and wheat were of prime interest to LACIE, the problem was approached with the objective of trying to accentuate those clusters that were prime candidates for being small grains or wheat.

From experience with the display procedure in the unitemporal mode, and after reference to results of work reported on by Wiegand (Wiegand, et al., 1977), a "soil line" decision boundary was defined at a 2x MSS 7/MSS 5 means ratio of 1.10.* That is, one could consider that for a given acquisition date, a cluster with a 2x MSS 7/MSS 5 means ratio greater than 1.10 represented a spectral subclass of green vegetation.

The term "soil line" actually refers to the upper limit of a bare soil and/or dry vegetation distribution. The lower limit for green vegetation may be slightly lower than 1.10. Lowering the "soil line" ratio value, however, would allow much more bare soil and dry vegetation to be committed with green vegetation than the amount of green vegetation ommitted at the 1.10 ratio value.

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*Data not corrected for sun angle or haze.

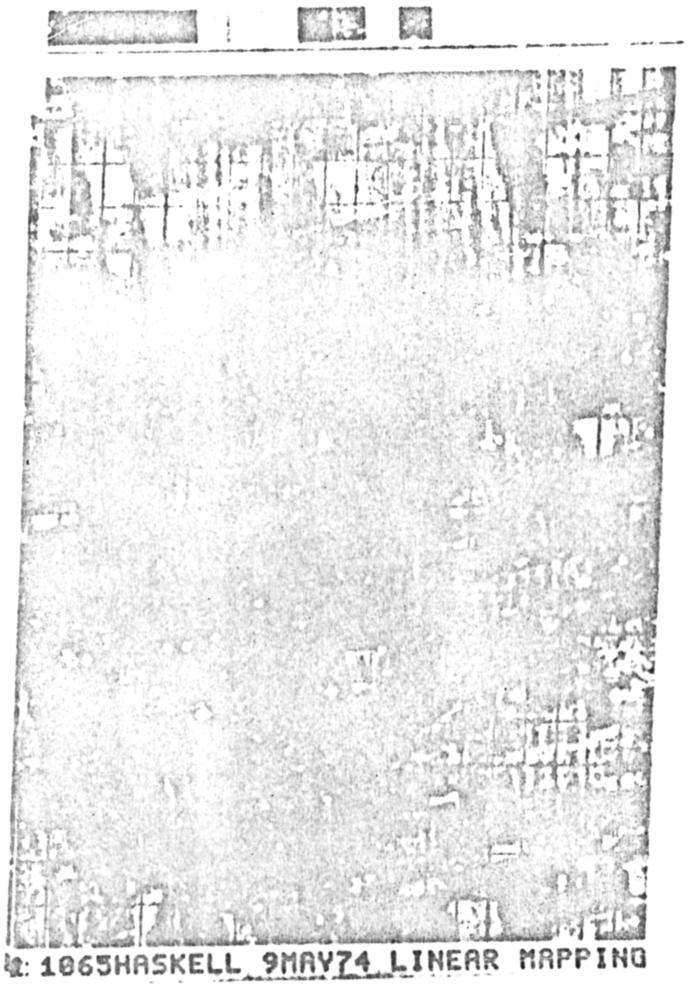

Figure 2.1 a)

Figure 2.1 b)

(See captions on facing page.)

Figure 2.1 a) Raw Landsat image for 9 May 1974 for segment 1065 Haskell County, Kansas. Most bright and dull red fields are wheat, with some bright red fields being alfalfa and sugar beets.

Rank #	2x MSS7/ MSS5 Ratio	Color	Cluster #
1	4.75	light red violet	2
2	4.24	med red violet	17
3	3.27	dark red violet	10
4	3.20	red	19
5	2.36	dark red brown	13
6	2.24	dark red orange	8
7	2.05	red orange	6
8	1.61	yellow orange	4
9	1.39	yellow	11
10	1.15	dark yellow gold	3

Figure 2.1 b) Unlabelled ordered cluster map produced from unlabelled cluster display procedure described in text. Note the preservation of landscape features, and analogous color assignments to related clusters within the same cropped fields. Red-violet hues are mostly alfalfa, sugar beets and some wheat. Red, red-orange, orange, and yellow hues are primarily wheat. Gold is pasture, wheat, and urban. Green is pasture or bare soil, and turquoise, blue, and blue violet are bare soil. Color boxes indicate cluster color assignment. Cluster #1 (first box) is ranked #19 by ordering procedure. See table below.

Rank #	2x MSS7/ MSS5 Ratio	Color	Cluster #
11	.95	light yellow green	20
12	.95	med yellow green	9
13	.92	medium green	7
14	.91	dark green	12
15	.90	light blue green	5
16	.89	dark blue green	14
17	.88	medium blue	16
18	.85	dark blue	18
19	.53	blue violet	1
20	Bad Data	black	15

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Figure 2.2 represents the temporal plot of the 2x MSS 7/MSS 5 ratio for winter wheat in Kansas in 1974. Similar plots can be generated for all major crops within an area. Information on temporal ratio plots for all major crops in an area allows an analyst to define a simple temporal function for each crop type. The temporal ratio function can be defined by the difference between the ratio value and the soil line value of 1.10 for each biostage represented.

The following cluster ordering procedure was used for multitemporal data. Clustering was carried out as described above for unitemporal data except that in the multitemporal case, four times the number of acquisitions, channels of data were clustered.

1) *The analyst defines the 2x MSS 7/MSS 5 ratio function for the given set of acquisitions for a segment to be processed. He then selects a cluster ordering reference acquisition date. This acquisition is the one on which the analyst determines that wheat is probably most discriminable from (unitemporally) all other conditions/crop types present in the segment.*

2) *The clusters are ordered according to the 2x MSS 7/MSS 5 ratio of the cluster means on the reference date, proceeding from the highest ratio to the lowest.*

3) *After the multitemporal clusters have been ordered by the 2x MSS 7/MSS 5 ratios on the reference date, the ratio of 2x MSS 7/MSS 5 means for all other acquisitions processed are recorded in proper temporal order along side the reference date ratio for each cluster.*

4) *The difference (or delta) between the ratios for each pair of adjacent acquisitions is noted, and the position of the ratio, above or below the soil line (1.10), is noted.*

5) *Referring to the temporal MSS 7/MSS 5 ratio functions for small grains/wheat and other major crop types within a region, the analyst assigns each cluster to a stratum based on the probability that the cluster is a small grains cluster. Three main strata can consistently be broken out. (An option is available to the analyst to define two substrata for each stratum if he so desires; however, the strata are bounded by the main strata definitions.) The three main strata based on their temporal 2x MSS 7/MSS 5 ratio delta function relative to the defined soil line are:*

   a) *High probability small grains stratum: probability $\geq$ 50% that the cluster is small grains*
   b) *Medium probability small grains stratum: $\geq$ 25% to $\leq$ 50% probability that the cluster is small grains. This stratum seems to contain primarily pasture, alfalfa, and range clusters in winter wheat areas.*

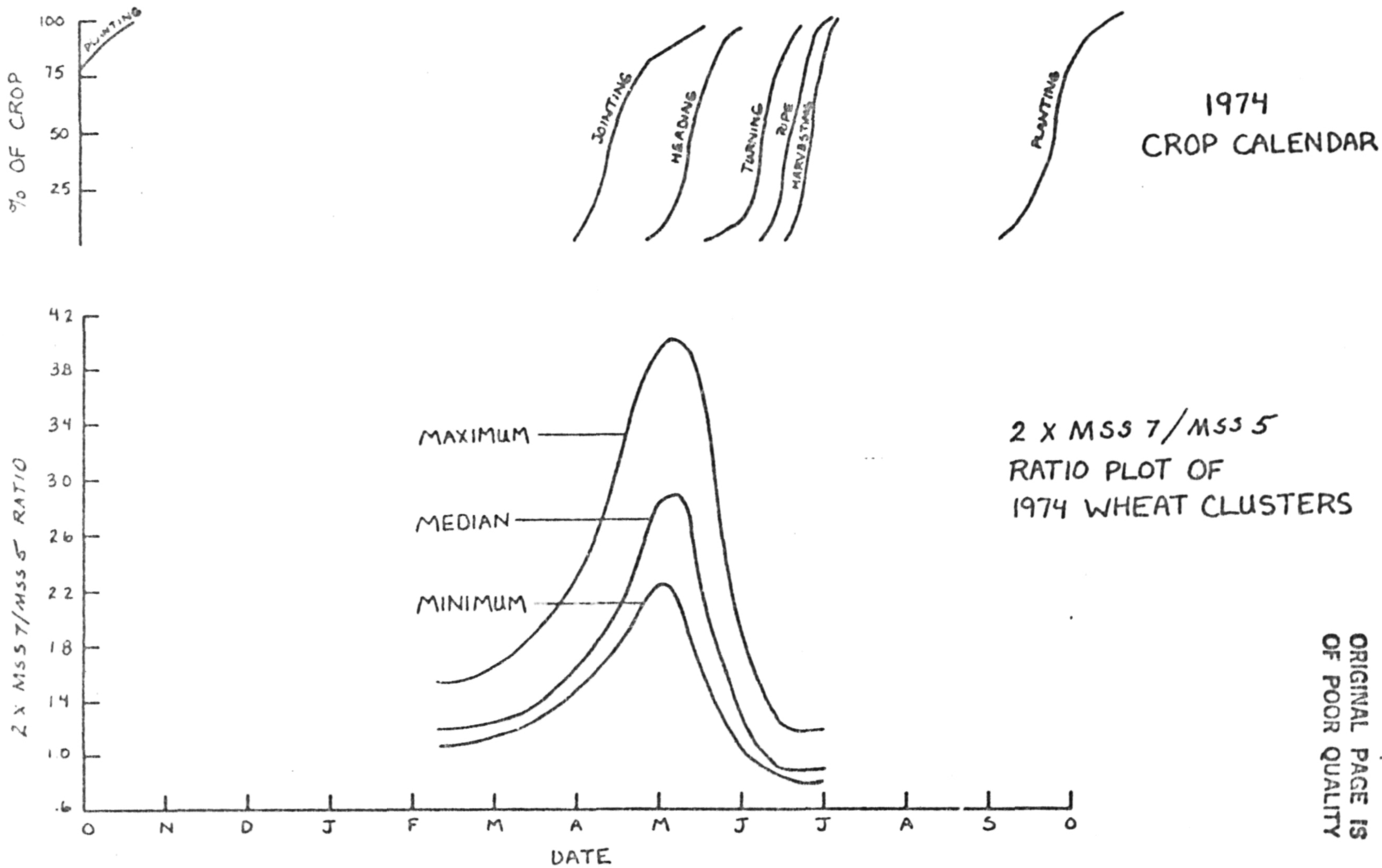

Figure 2.2 Example of 2x MSS 7/MSS 5 ratio plot of winter wheat in Kansas compared to standard wheat crop calendar data.

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c) *Low probability small grains stratum: $\leq$ 25% probability that a cluster is small grains. This stratum usually contains summer crops such as corn or sorghum or fallow conditions. Table 2.3 is an example of cluster assignment to small grains probability strata using the above described procedure.*

6) *Once the clusters are assigned to strata, the analyst then defines the display function for the clusters. The function is defined so that clusters within the same stratum or substratum will visually group together when displayed. This is necessary so that the analyst can efficiently analyze the spacial distribution of related clusters. Visual grouping can be accomplished in two ways: (1) by assigning the same color code to all clusters in the same substratum (this does not optimally allow for analysis of individual clusters); or (2) by assigning analagous (adjacent) colors (e.g. red and orange, yellow and yellow green, blue green and blue) to adjacent clusters within a substratum as ordered by their 2x MSS 7/MSS 5 ratios on the reference date. If there is a limitation in the number of unique, and visually separable available colors, multiple images can be used. In this case, individual ordered clusters within a given substratum are displayed in adjacent spectrally ordered colors. Clusters within the remaining substrata are grouped by substrata and displayed in a single, common color specific to each of the remaining substrata.*

While DFS was developed initially as a display procedure for unlabelled multitemporal cluster maps, it soon became apparent that the procedure produced a stratification that offered some potential improvement over Procedure 1. Initially during this last year, the Delta Function Stratification Procedure has been developed using a full season's set of acquisitions (i.e. at harvest procedure). However, after being developed and tested for an at-harvest mode, continuing development of the procedure will concentrate on mid and early season estimation capabilities.

Table 2.3 *Example of Unlabeled Multitemporal Clusters Strata Assignment*

Segment #1041, Meade County, Kansas

Stratum Assignment	Cluster #	2x MSS 7/MSS 5 Ratio on Acquisition Dates & (Robertson Biostages)			% of Segment
		15 May 76rd* (3.5-4.0)	2 June 76 (4.5-5.0)	8 July 76 (7.0 +)	
Ma	38	3.17	1.36	1.23	0.19
Ma	56	2.60	1.41	1.39	0.27
Ha	55	2.49	2.07	0.86	0.29
Ha	30	2.15	1.85	0.93	2.38
Ha	15	1.89	1.93	0.97	2.90
Hb	44	1.87	0.89	0.98	0.20
Mb	10	1.42	1.75	1.39	3.58
La	4	1.00	0.85	0.86	2.89
Lb	37	0.97	0.87	1.86	0.66
Lb	40	0.97	1.19	2.24	0.23

*Reference Date

High Probability Small Grains Strata

Ha = (>1.10, >1.10, <1.10)
Hb = (>1.10, <1.10, <1.10)

Medium Probability Small Grains Strata

Ma = (>1.50, >1.10, >1.10
Mb = (>1.10 & <1.50, >1.10, >1.10)

Low Probability Small Grains Strata

La = (<1.10, <1.10, <1.10)
Lb = (<1.10, anywhere, >1.10)

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2.4.2.2 Evaluation of the DFS Procedure

The Delta Function Stratification procedure was evaluated in terms of processing efficiency, ease of use, and segment proportion estimate accuracy. An experimental design was developed for the last of these three criteria. In this design, thirteen separate procedures for estimating segment wheat proportion in Kansas or small grains proportion in N. Dakota were compared. These procedures (i.e. levels of factor P, for "procedure") were of three basic types: (1) a control treatment in which segments were processed according to the JSC/LACIE Fields Procedure; (2) a bias-corrected Fields Procedure; and (3) a bias-corrected DFS Procedure.

The rationale for the use of these three treatment types developed as follows. At the beginning of the contract period, the Fields Procedure was selected as the most logical basis for treatment comparisons since it had been and continued to be the JSC/LACIE standard. Much later in the contract year, however, JSC implemented the new Procedure 1 (P-1) wheat proportion estimation procedure. Within the time requirements of the contract period it was not possible to redo the control treatment using P-1. Thus UCB elected to compare DFS with a "simulated" P-1 treatment as well as with the older Fields Procedure. The simulated P-1 was developed by bias-correcting the Fields Procedure class map using bias-correction dots (a subset of the 209 grid intersections formed by placing a 10x10 grid over a sample segment) specified by P-1. The stratification resulting from DFS was also bias-corrected with the same dots.

The major differences between the simulated P-1 and P-1 as implemented at JSC were (1) the UCB classmap for the Fields Procedure was unitemporal as opposed to multitemporal as in P-1; and (2) the classifier was trained with analyst defined fields (as per Fields Procedure specification) as opposed to labelled clusters as in P-1. Table 2.4 summarizes steps involved in the Fields Procedure as it was implemented at JSC and simulated at UCB.

In order to evaluate the impact of analyst (AI) labelling error on the final segment wheat or small grains proportion estimates, the bias-corrected Fields Procedure and the bias-corrected DFS Procedure were each subdivided into ground and analyst dot labelling treatments. The effect of labelling dot sample size was examined by defining three sample sizes (60, 99, 209) within each bias-correction/labelling procedure. Consequently, each bias-corrected procedure (simulated P-1 and DFS) was represented by six treatment combinations.

Five segments were selected in Kansas and five in North Dakota on which to perform the procedure evaluation. These segments represented the range of agronomic and field pattern situations found in the wheat producing environment in both states. Each segment was processed with Fields and DFS Procedures and then subjected to dot labelling. Pixels falling under the 209 10x10 grid intersections were labelled by the same analysts assigned to each segment for the Fields Procedure processing. Finally, blind site ground data maps for each segment were

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Table 2.4 Summary of the JSC/LACIE Fields Procedure and the Simulated Fields Procedure Used by UCB

JSC/LACIE Fields Procedure

On the PFC transparencies and Landsat data:

1. *Define spectral subclasses by analysis of the full segment.*
2. *Select training fields from within spectrally homogeneous areas to represent all subclasses defined in Step 1.*
3. *Identify all spectral subclasses as wheat or non-wheat using multitemporal interpretation procedures.*
4. *Select five test fields which have not been selected as training areas.*
5. *Digitize and verify training and test field coordinates using a coordinatograph and the LARS terminal.*
6. *Submit segment for batch classification processing.*
7. *Evaluate the classification results using class map and performance matrix for training and test areas.*
8. *If necessary, modify training and submit for reclassification.*

UCB - Simulation of the JSC/LACIE Field Procedure

1. *On the PRC transparencies, define subclasses according to JSC procedures.*
2. *Select training fields according to JSC procedures.*
3. *Identify as wheat or non-wheat all subclasses using JSC procedures.*
4. *Systematically select fifty test areas throughout the segment. (It is UCB's view that the five test areas as required by JSC procedures are insufficient for an adequate evaluation of the classification results.)*
5. *Extract training and test field coordinates using the UCB-Remedys color monitor display system. A coordinatograph as used at JSC is not available at UCB.*
6. *Submit the training deck to the supervised classifier (CALSCAN) for processing.*
7. *Evaluate the classification results using the class map and performance matrix for training and test areas.*

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cut into small grains/wheat versus other stacks and then weighed to produce the base line wheat proportion percentages. These percentages were subtracted from the corresponding small grains or wheat percentages obtained in each of the thirteen estimation procedures. The resulting difference (error) formed the response variable used in the analysis of variance discussed in the next section. Figure 2.3 and Table 2.5 illustrate the resultant DFS stratifications for several of the test segments in Kansas and North Dakota.

2.4.3 RESULTS AND DISCUSSION

In order to determine if there was a significant difference between wheat and/or small grain estimates produced from the (1) Fields Procedure (P=13); (2) bias-corrected Fields Procedure (p=1-6,; and (3) bias-corrected DFS (p=7-12), a one-way analysis of variance (ANOVA) on the thirteen treatments means was performed. The results of the one-way ANOVA analysis are shown in Tables 2.7, 2.9 and 2.11. They show no significant difference among treatents for Kansas and North Dakota treated together (α=.591) and no significant difference for Kansas (α=.981) or North Dakota (α=.770) treated separately. It is possible, however, to construct two-way analyses of variance tables for the factors - 1) treatment (P) and 2) segment (SEG), using numbers from SPSS* printouts of the separate one-way ANOVAs. The accompanying Tables 2.12, 2.13 and 2.14 are based on Tables 2.6 and 2.7, 2.8 and 2.9, 2.10 and 2.11, respectively. The treatment difference is significant at .05 level for Kansas and North Dakota treated together, but not for Kansas or North Dakota treated separately.

The general advantage of a two-way ANOVA table over a one-way ANOVA analysis may be explained as follows. Consider the effect P tested above, over all ten segments. In the one-way ANOVA the total sum of squares is partitioned into 287 due to the P factor (that is, between the means of the thirteen treatments) and 3263 due to error (that is, error within the thirteen treatment groups). The total sum of squares is 3550. By contrast in the two-way ANOVA, the 3263 sum of squares associated with the error in the one-way ANOVA is broken into two parts - 2092 due to the segment (SEG) factor and 1170 due to error. Given that the significance of the effects of any factor is tested with the ratio

$$F = \frac{\text{sum of squares due to effect/degrees of freedom}}{\text{sum of squares due to error/degrees of freedom}},$$

we can see that to evaluate the significance of the P effects, it is necessary to first remove the large effect due to segment.

Note that the two-way ANOVA tables cited above were actually based on one case per cell, and could thus not be computed by SPSS. The disadvantage of this design is that the interaction** effect cannot

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*Statistical Package for the Social Sciences

**In a replicated two-way ANOVA, write the model as

$$y_{ijk} = m + R_i + C_j + I_{ii} + \varepsilon_{ijk}.$$

Then R_i, C_j, and I_{ii} are the row, column and interaction effects, respectively.

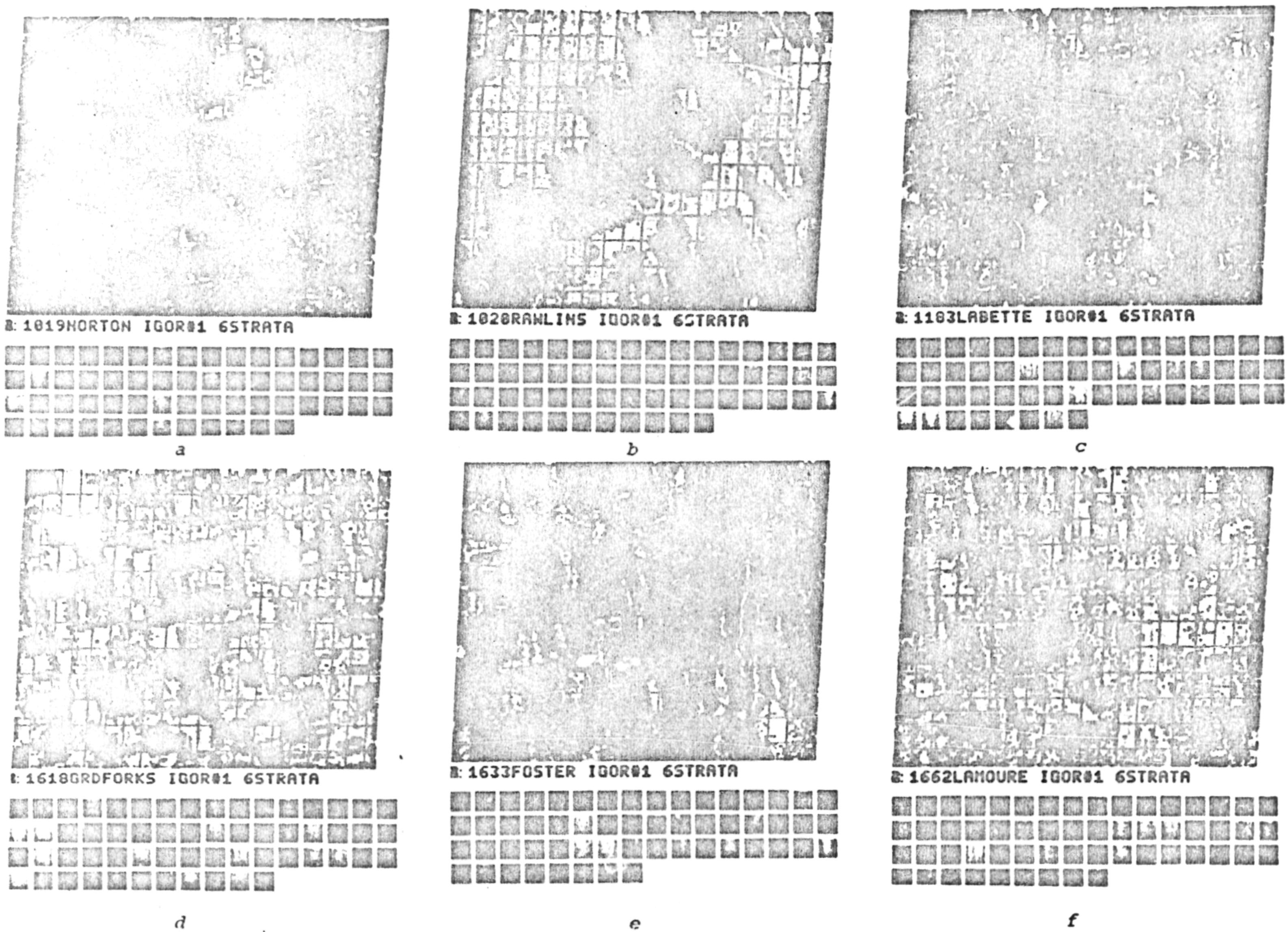

Figure 2.3 Resultant DFS Small Grains Probability Stratification for several test segments from Kansas (a-c) and North Dakota (d-f). Red and yellow are high probability small grains strata, green and blue are medium probability small grains strata, and gray and violet are low probability small grains strata. Distribution of wheat and small grains within each stratum by segment is shown in Table 2.5.

Table 2.5

KANSAS

a. Percentage of Total Wheat in a Segment Falling in Each Stratum

Segment #	1019	1020	1035	1041	1183
Stratum					
Ha	72.6	43.9	51.3	68.2	51.9
Hb	13.7	30.3	2.6	2.3	7.4
Ma	4.1	0.0	----	0.0	18.5
Mb	8.2	18.2	2.6	15.9	22.2
La	1.4	6.1	38.5*	13.6*	0.0
Lb	0.0	1.5	5.1	0.0	0.0

*Much abandoned wheat

b. Wheat Proportion Within Each Stratum

Ha	81.5	96.7	64.5	69.8	70.0
Hb	33.3	100.0	6.3	25.0	100.0
Ma	18.8	0.0	----	0.0	3.4
Mb	30.0	14.3	1.9	13.5	24.0
La	1.3	6.9	22.1*	5.6*	0.0
Lb	0.0	8.3	5.0	0.0	0.0

c. Percentage of Segment in Stratum

Ha	28.9	14.0	21.1	20.8	9.4
Hb	14.6	10.3	4.7	2.6	1.9
Ma	8.1	1.6	2.8	.8	72.8
Mb	12.5	40.5	29.0	25.1	11.2
La	34.7	27.7	14.9	45.6	.6
Lb	1.2	6.0	27.4	5.1	4.1

Table 2.5, continued

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NORTH DAKOTA

d. Percentage of Total Wheat & Small Grains Falling in Each Stratum

SEG #	1618		1624		1633		1645		1662	
Stratum	W	SG	W	SG	W	SG	W	SG	W	SG
Ha	52.9	70.5	77.1	68.2	86.5	66.7	84.8	90.3	48.6	60.0
Hb	----	----	----	----	10.2	33.3	0.0	0.0	9.7	0.0
Ma	3.4	6.8	9.4	13.6	3.4	0.0	4.8	3.2	15.3	13.3
Mb	39.1	15.9	5.2	9.1	0.0	0.0	8.6	3.2	20.8	20.0
La	0.0	0.0	5.2	9.1	0.0	0.0	----	----	1.4	0.0
Lb	4.6	6.8	3.1	0.0	0.0	0.0	1.9	3.2	4.2	6.7

e. Wheat/Small Grain Proportion Within Each Stratum

Ha	55.4	92.8	64.9	78.0	76.8	78.8	65.4	86.0	60.3	75.9
Hb	----	----	----	----	19.6	21.7	0.0	0.0	77.8	77.8
Ma	14.3	28.6	36.0	48.0	10.0	10.0	25.0	30.0	31.4	37.1
Mb	70.8	85.4	21.7	30.4	0.0	0.0	45.0	50.0	22.4	26.9
La	0.0	0.0	50.0	70.0	0.0	0.0	----	----	12.5	12.5
Lb	7.1	12.5	8.1	8.1	0.0	0.0	6.4	9.7	9.4	12.5

f. Percentage of Segment in Stratum

Ha	40.4	52.9	40.8	65.7	31.7
Hb	----	----	20.8	.6	4.3
Ma	9.5	12.4	19.5	7.6	13.2
Mb	23.9	14.6	9.5	11.2	32.6
La	1.0	5.1	6.9	.7	2.1
Lb	25.1	15.0	2.5	14.2	16.1

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Table 2.6 Analysis of Variance Kansas and North Dakota Together

	D.F.	S.S.	M.S.S.	F	α
Between SEG	9	2092.28	232.48	19.143	0
Within SEG	120	1457.29	12.14		
Total	129	2549.57			

Table 2.7 Analysis of Variance Kansas and North Dakota Together

	D.F.	S.S.	M.S.S.	F	α
Between P	12	287.03	23.92	.858	.591
Within P	117	3262.54	27.88		
Total	129	3549.57			

Table 2.8 Analysis of Variance Kansas Segments Alone

	D.F.	S.S.	M.S.S.	F	α
Between SEG	4	1144.52	286.13	40.47	.00
Within SEG	60	424.52	7.07		
Total	64	1568.72			

Table 2.9 Analysis of Variance Kansas Segments Alone

	D.F.	S.S.	M.S.S.	F	α
Between P	12	109.61	9.13	.326	.981
Within P	52	1459.11	28.06		
Total	64	1568.72			

Table 2.10 Analysis of Variance North Dakota Segments Alone

	D.F.	S.S.	M.S.S.	F	α
Between SEG	4	779.94	194.99	11.32	.00
Within SEG	60	1033.09	17.22		
Total	64	1813.04			

Table 2.11 Analysis of Variance North Dakota Segments Alone

	D.F.	S.S.	M.S.S.	F	α
Between P	12	243.22	20.27	.671	.770
Within P	52	1569.82	30.19		
Total	64	1813.04			

Table 2.12 ANOVA Table for ten (Kansas and North Dakota together) segments and 13 treatments

	D.F.	S.S.	M.S.S.	F
P	12	287.03	23.92	2.21
SEG	9	2092.28	232.48	
ERROR	108	1170.26	10.84	
TOTAL	129	3549.57		

If all treatment means are the same, then

$$F = 9.\frac{SSp}{SS_E} = 9.\frac{MSSp.12}{MSS_E 9.12} = \frac{MSS_R}{MSS_E} = \frac{23.92}{10.84} = 2.21$$ has the F distribution with 12 and 108 d.f.

$F(.05;\ 12,108) = 1.85$ and $F(.01;\ 12,108) = 2.36$. Thus $\alpha = .01$ and the difference between treatments is definitely significant at the .05 level.

Table 2.13 ANOVA Table for five Kansas segments alone and 13 treatments

	D.F.	S.S.	M.S.S.	F
P	12	109.61	9.13	1.43
SEG	4	1144.52	286.13	
ERROR	48	314.59	6.55	
TOTAL	64	1568.72		

Ho: all treatment means same

$$F = \frac{MSS_P}{MSS_E} = \frac{9.13}{6.55} = 1.43$$

$F(.05;\ 12,65) = 1.90$

$F(.01;\ 12,65) = 2.47$

Thus treatment means not significantly different.

Table 2.14 ANOVA Table for five North Dakota segments alone and 13 treatments

	D.F.	S.S.	M.S.S.	F
P	12	243.22	20.27	1.23
SEG	4	799.94	194.99	
ERROR	48	789.88	16.46	
TOTAL	64	1813.04		

Ho: all treatment means same

$$F = \frac{MSS_P}{MSS_E} = \frac{20.27}{16.47} = 1.23$$

$F(.05; 12,65) = 1.90$

$F(.01, 12,65) = 2.47$

Thus treatment means not significantly different.

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be estimated. By comparing these tables with others in which the interaction is estimated, the interaction was judged highly significant. The tests of significance of the main effects of a two-way table (in this case, the thirteen treatments (P) as one effect, the segments (SEG) as the other) are less valid when the interaction is significant than it would be if the interaction were not significant.

In each of the remaining two-way tables discussed, there are several cases per cell, and thus a third effect, the interaction effect, is estimated from the variability within the cells. Then each of the three effects (two main effects and the interaction effect) are tested against the error term as described above. The interaction effect is tested first. If it is not significant then the significance tests on the main effects are valid. If the interaction is significant, the results are of doubtful validity, but may serve as a useful guide to formulate new hypotheses to be tested.

We saw in the preceding section that a two-way table of P and SEG (10 segments) showed a significance level of approximately .01 for P but that was of doubtful validity due to the probability of a significant interaction. However, as was noted above in the preceding paragraph, the results can be used as a guide to formulating further hypotheses. The first twelve treatments of the total thirteen levels of P form the two-way Table 2.15. We may now hypothesize that the factors 1) dot sample SIZE or 2) PS, or both are significant. The alpha levels of one-ways on each of these factors and alpha levels of their corresponding effects in a two-way ANOVA are given in Tables 2.16 and 2.17.

We can see from the first row of Table 2.16 that a one-way on PS for all ten segments is significant at the .05 level (30 cases per cell). However, PS is not significant for either state alone due to the small sample size (15 cases per cell).

A one-way ANOVA on dot sample SIZE showed size not to be significant.

The two-way of PS and SIZE (Table 2.17) for both states combined is marginally significant overall (α=.13). With the variability due to PS removed we see that the significance level of SIZE is much lower (.999).

In the above one-way ANOVAs and two-way ANOVAs we again have the problem that most of the variability is due to the segment effect. It is still possible that in a two-way ANOVA with SEG, the factor sample SIZE may be significant, and that a much higher significance level with PS may be found.

Table 2.15 Treatment (Procedure) Group

Dot Sample Size	PS=1 (BCFP*/AI)	PS=2 (BCFP/GT)	PS=3 (DFS/AI)	PS=4 (DFS/GT)
1 (109)	p = 1	4	7	10
2 (99)	2	5	8	11
3 (60)	3	6	9	12

(p = 13 is the fields procedure)

*BCFP = Bias Corrected Fields Procedure

Table 2.16

	K/ND	K	ND
PS	.048	.294	.207
SIZE	.576	.919	.352

Table 2.17

	K/ND	K	ND
OVERALL	.126	.999	.301
PS	.057	.360	.247
SIZE	.999	.999	.999
INTERACTION	.999	.999	.999

Table 2.18

	K/ND	K	ND
OVERALL	.001	.001	.001
PS	.001	.001	.014
SEG	.001	.001	.001
INTERACTION	.022	.001	.999

Table 2.19

	K/ND Combined	K	ND
OVERALL	.001	.001	.001
SIZE	.136	.999	.032
SEG	.001	.001	.001
INTERACTION	.005	.999	.999

Table 2.20 Wheat (Kansas)/small grains (North Dakota) Proportion Estimates Averaged by Stratification and Labelling Procedure

	Bias Corrected Fields Procedure	DSF
Analyst Labels	-1.52	-2.68
Ground Labels	0.64	0.25

Table 2.21 Significance Levels Resulting from a Two-Way Analysis of Variance of the Stratification Labelling Factors

	K/ND Combined	Kansas	North Dakota
OVERALL	.020	.159	.111
STRATIFICATION FACTOR	.999	.999	
LABELLING FACTOR	.008	.077	.039
INTERACTION	.999	.999	.999

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Tables 2.18 and 2.19 show the impact on significance levels for PS and SIZE when the effect of SEG is removed. In both two-ways based on the two states combined, the interaction was highly significant and so the significance levels for the main effects are doubtful, although the .136 for SIZE is probably indicative of lower significance for sample SIZE than for PS (α=.001).

For Kansas alone there is no significant interaction of SIZE with SEG, and thus we can conclude emphatically that SIZE is not significant: .999 for SIZE as a main effect while .001 overall.

For North Dakota alone there is no significant interaction of PS with SEG and thus we can conclude that PS is highly significant (α=.014).

Since there is no evidence that SIZE is a significant factor, and some indication that it is not, we may dismiss it as contributing significantly to the variability among the thirteen levels of P. We have already seen that PS is significant at the .05 level in a one-way by itself. Thus four groups of three levels each of the thirteen have been shown to be significantly different.

The four PS group response (predicted minus actual) means are given in Table 2.20.

We see in Table 2.20 that the four PS lebels are expressed in terms of two factors 1) segment stratification procedure and 2) labelling procedure. It appears that the major difference is due to labelling procedure. To test this observaiton the two-way analysis of variance summarized in Table 2.21 was performed. The results of the analysis on both states combined shows that the labelling treatments are in fact significantly different at the one percent level. Both the stratification factor and the factor interaction terms are not significant. The analyses for Kansas and North Dakota separately show a less significant (due to the lower sample size), but similar pattern.

The final conclusions from these analyses are that:

1. *There is a significant difference between wheat proportion estimates produced from analyst labelled bias-correction dots vs. ground data labelled bias-correction dots, but*
2. *there is no significant difference between wheat proportion estimates produced from bias-corrected fields procedure vs bias-corrected DFS.*
3. *There is no significant difference detected in wheat proportion estimates due to bias-correction dot sample size although a trend did seem to indicate a decrease in wheat proportion error with the larger sample sizes. Thus a bias-correction dot sample size of 99 (first and second prioity type two dots from P-1) is recommended.*
4. *Sampling error for the stratified bias-corrected procedures at the 99 dot sample size have been calculated along with the*

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sampling error for an unstratified dot sample of 209 points. While a slight decrease in sampling error was observed for the stratified samples over the unstratified sample, the differences did not appear to be significant.

Thus from the at-harvest testing of DFS, it appears that DFS can be considered comparable to results from P-1. In addition, DFS has some advantages over P-1. The principle advantages of DFS over P-1 are:

1. *Analyst segment handling time is potentially reduced since only bias-correction dots are labelled and no starting or labelling dots need be labelled. Analyst interpretation times for the various procedures tested are shown in Table 2.22.*
2. *There is no dependence on an automatic labelling algorithm for unsampled clusters. Each cluster's statistics are examined and assigned to a stratum on its own merits. Thus the quality of the strata assignment decision is theoretically the same for each cluster.*
3. *DFS can eliminate the need for applying the maximum likelihood classifier as in the LACIE situation. The stratification produced from DFS can be sampled in the same manner as the stratification produced in P-1 from the maximum likelihood classifier. This eliminates one costly automatic processing step.*
4. *DFS Shows potential for automation so that the analyst need only label "bias correction" dots. This reduces the data handling by analysts on an individual segment.*
5. *By stratifying the segment into small grains probability strata, a separate estimate of mean and variance can be produced for each stratum. This potentially allows more precise estimates for wheat to be made at the segment level.*
6. *It may be possible to combine DFS with Procedure B (being developed by ERIM) to produce strata from multi-segment data. These multisegment strata could then be sampled to produce small grains/wheat estimates.*
7. *While DFS was optimally developed for small grains, the resulting stratification can probably be applied to the multicrop situation with only minor modifications.*

DFS as tested used 2x MSS 7/MSS 5 ratios as the vegetation indicator. Any vegetation indicator could be utilized, however, provided the variance around the soil line decision boundary is comparable to that of the 2x MSS 7/MSS 5 ratio. Thus DFS may work equally well with Tasselled Cap Transformation band 2 (greeness numbers) as the vegetation indicator.

It is recommended that testing of DFS be continued to determine

1. *its performance for the production of mid- and early-season estimates;*
2. *its performance using Tasselled Cap greeness values as the vegetation indicator; and*
3. *its applicability in the multisegment processing situation.*

Table 2.22 Analyst Interpretation Times for Evaluated Procedures

	Interpretation-Training Time	Stratification Time	Estimate Calculation	Total
Fields Procedure	11 hrs		15 min	11 hrs 15 min
Bias Corrected Fields Procedure	11 hrs		20 min	11 hrs 20 min
	(1-2 hrs)		20 min	1 hr 20 min 2 hrs 20 min
DFS/Bias Corrected 209	2 hrs	15 min*	20 min	2 hrs 35 min
99	1 hr	15 min*	20 min	1 hr 35 min
60	40 min	15 min*	55 min	1 hr 50 min

*Potential for automation

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2.5.0 SUBTASK C: EXPLORATION OF MULTITEMPORAL DATA COMPRESSION PRODUCTS

2.5.1 OBJECTIVE

The objective of this subtask was 1) to explore methods for reducing the dimensionality of Landsat multitemporal-multispectral data; and 2) to evaluate the role of data reduction products in multitemporal interpretation procedures. Of prime concern for this task was the development of data reduction products for which an analyst could develop logical and consistent expectations.

2.5.2 APPROACH

Of all the available Landsat data, temporal development patterns of vegetation canopy are most exploitable for crop type identification. Certain Landsat vegetation indicators (VI) such as the 2x MSS 7/MSS 5 ratio and the Tasselled Cap Transformation greeness values have been shown to correlate well with vegetation development (Weslaco, 1977; ERIM, December 1977). Thus 2x MSS 7/MSS 5 and the linear combination K2 = -.28317MSS4 -.66006MSS5 +.57735MSS6 +.38833MSS7 (greeness band from Tasselled Cap Transformation) were chosen for initial study. In addition, both of the above indicators serve as an initial dimensionality reduction of the Landsat unitemporal-multispectral data.

2.5.2.1 PRODUCTS EVALUATED

Image Products

Products were produced in two different formats: an image format, and a numeric format. In the production of image formatted data products, an attempt was made to represent wheat (the crop of interest) with colors from the yellow to red hue regions or with colors from the white region (brightest valued colors) of color space. The red to yellow hues and the brightest (whitish) values were chosen for display of the data of most interest, because the red-yellow hue region of color space has the largest number of distinguishable (to the human eye) hues within the shortest distance in color space (see Figure 2.4). Thus spectral differences between features are more likely to be detected within data mapped to this region of color space. In addition, since yellow is the brightest, maximumly saturated "visual primary", and white the brightest value (see Figure 2.5), the eye will be immediately attracted to the fields with the higher probability of being wheat.*

Two different approaches to data reduction were explored for image formatted data products. The first approach consisted of a single combination of the vegetation indicator data from three acquisition dates into one color composite image. The VI data (2x MSS 7/MSS 5 or K-2) for three acquisition dates were photographically or electronically com-

**Visual (human eye) primarys are red, blue and yellow, as opposed to the color additive primaries for color monitors of red, blue, and green. The human eye does not see green as a primary, but as a mixture of blue and yellow.*

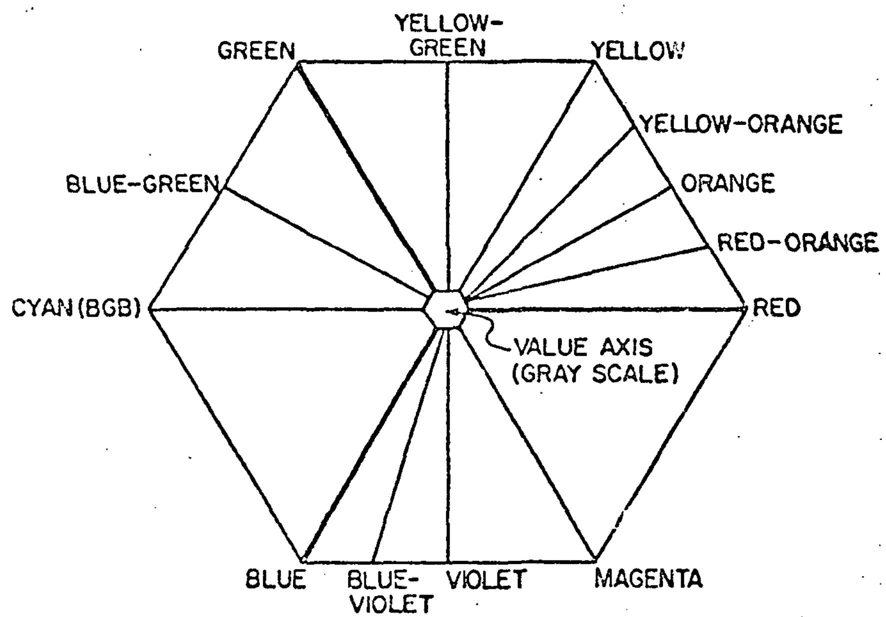

Figure 2.4 Looking down along the value (brightness-darkness) axis in Munsell coordinated color space, one can see that a larger number of distinguishable colors lie between the red and yellow hues than between any other primary and its adjacent secondary colors.

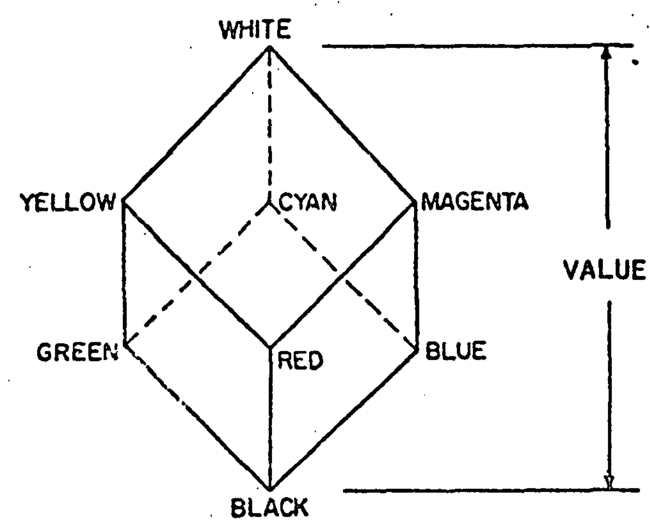

Figure 2.5 Looking perpendicular to the value axis in Munsell coordinated color space one can see that yellow is the highest valued (brightest) maximumly saturated visual primary, and that white is the brightest color.

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bined to produce a single multitemporal composite image. The date specific VI data was assigned to one of three color guns or emulsion layers. A "soil line" or more properly a green vegetation decision boundary was placed in the data and aligned among the three dates that comprised the image. For the 2x MSS 7/MSS 5 ratio the soil line was placed at a ratio of 1.10; for sun angle and haze corrected K-2 data the soil line was placed at eight green numbers above the one percentile level in the data. All data falling below the soil line was assigned to the zero (off) level of one of the color guns in the display system. All data falling above the soil line was mapped to the other color gun levels using histrogram equalization (equal areas under the curve). Histogram equalization of data above the soil line serves to maximuze data contrast. Linear mapping of data above the soil line was also examined to a limited extent.*

Alignment of the soil line from several acquisitions allows the analyst to directly interpret the resultant image according to expectations developed from wheat crop calendar data. The analysts expectations are as follows: 1) wheat will be above the soil line after the threshold of detectable canopy (suspected at ≈ 20% canopy cover) has been reached. This detectable canopy cover percentage occurs somewhere between emergence and jointing in wheat. From detectability (pre-jointing) through the start of heading, VI's for wheat fields will generally continue to increase above the soil line. Around heading, the peak value of the VI will occur and after heading the VI for wheat will generally decrease. The VI for wheat post-heading will remain above the soil line (though decreasing) until some point between turning and dead ripe when it passes below the soil line for 2x MSS7/MSS 5 data. In K-2 data it will remain slightly above the soil line. Table 2.23 indicates the image colors that an analyst can expect for various combinations of green vegetated and non-green vegetated phases for a field. By knowing the wheat biostage for each combined acquisition an analyst can predict the color or colors in which wheat fields will be displayed for a given composite image. Examples of image products produced using this procedure are shown in Figure 2.6 a-m. A limitation of this procedure is that the data from only three acquisitions can be combined into one image. The second approach to this problem does not have this acquisition limitation.

*The second approach to data dementionality reduction for image formatted data involved the application of principal component analysis to a set of VI's for four or more acquisitions.** The first three resultant principle components (eigen vectors) from these analyses are assigned to the three color guns of a display system to produce an image of the new data. Image products from principle component analysis of the K-2 data were qualitatively examined and compared to the previously described image products. Examples of the principle component image products are shown in Figure 2.7.*

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*This is similar to the procedure utilized by Oscar Wehmannen of LEC, Houston.
**Abotten, LEC, 1977.

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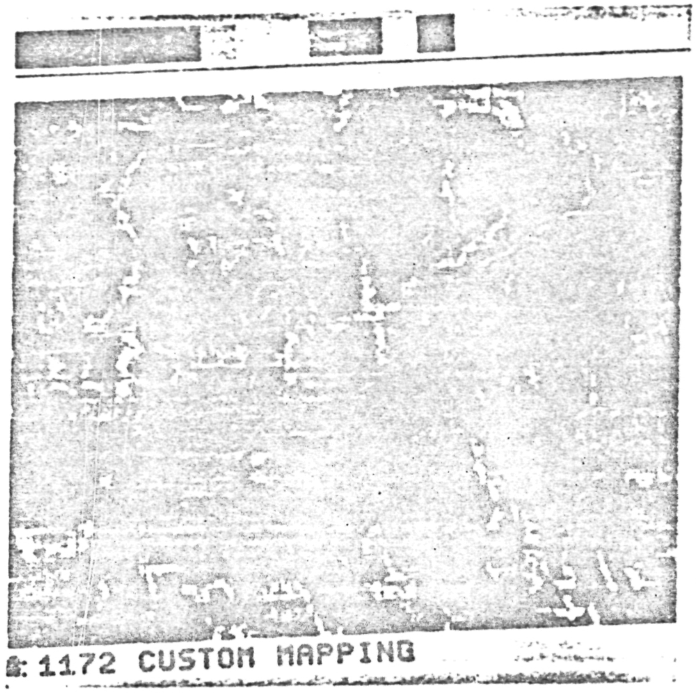
Table 2.23 *This table indicates the image color that an analyst can expect for the various combination of green vegetated and non-green vegetated phases when assigned to the color guns as below. Thus an analyst can predict the color or colors to expect for wheat in the multitemporal composite images by knowing the wheat biostages for the combined acquisition dates and the color gun assignment.*

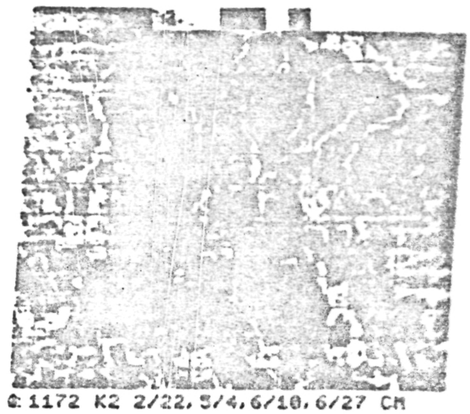
color gun / *acquisition*	*red* *1*	*green* *2*	*blue* *3*	
	o	*o*	*o*	*black (fallow)*
	o	*o*	*x*	*blue*
	o	*x*	*o*	*green*
	o	*x*	*x*	*cyan*
	x	*o*	*o*	*red*
	x	*o*	*x*	*magenta (not probable in wheat)*
	x	*x*	*o*	*yellow*
	x	*x*	*x*	*white*

x - indicates green vegetation stage (i.e. above "soil line")

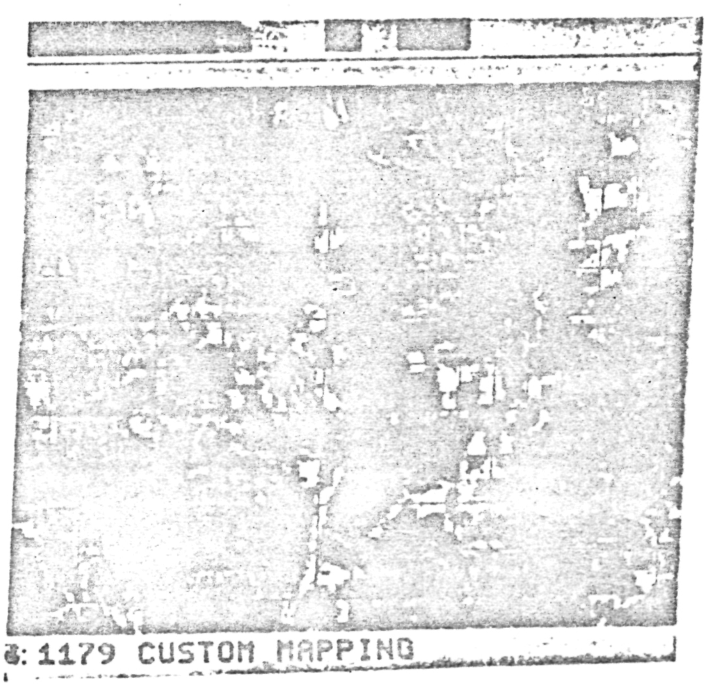
o - indicates dry vegetation stage, or bare soil stage (i.e. below "soil line")



2.6a



2.6b



2.6c

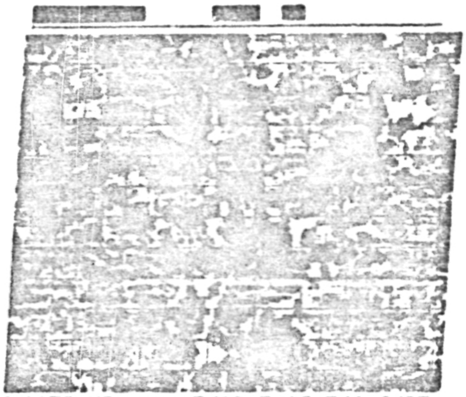
2.6d

Figures 2.6a and 2.6b

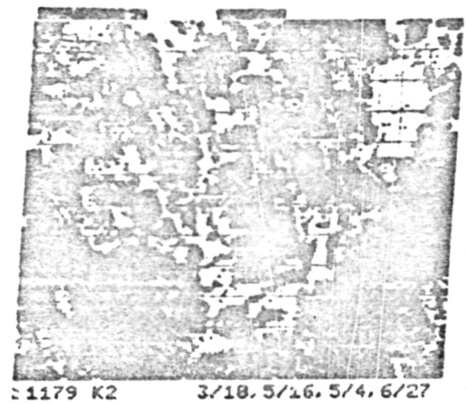
Kansas segment 1172. Multitemporal composite of the vegetation indicators 2x MSS 7/MSS 5 (Figure 2.6a) and Tasselled Cap band 2 (K-2) (Figure 2.6b) for February 22 - wheat fields greening up after dormancy (red gun); May 4 - wheat fields jointed to headed (green gun); and June 27 - wheat fields turned (blue gun). Referring to Table 2.23 indicates wheat fields should be displayed in the yellow region of color space. Green fields in these images are mostly late emerging wheat fields. Blue areas are pasture and some summer green up crops such as sorghum. Comparison of Figure 2.6a and b indicates very little real difference between the MSS 7/MSS 5 and K2 multitemporal images.

Figures 2.6c and 2.6d

Kansas segment 1179. Multitemporal composite of the vegetation indicators 2x MSS 7/MSS 5 (Figure 2.6c) and the Tasselled Cap band 2 (K-2) (Figure 2.6d) for March 10 - wheat fields greening up after dormancy (red gun); May 4 - wheat fields jointed to headed (green gun); and June 27 - wheat fields turned (blue gun). Wheat fields should be displayed in the yellow region of color space. Some late greening up wheat fields are green, but more often pasture fields are green in this image. Noise (red speckles) in Figure 2.6d, the K-2 image, illustrates the problem of the variability in the soil line placement within the K-2 data on some dates.



2.6e



2.6f

Figures 2.6e and 2.6f Kansas segment 1179. Comparison of at-harvest and mid-season multitemporal composite images of the vegetation indicator K-2. Figure 2.6e is an at-harvest image comprised of acquisitions for March 10 - wheat greening up (red gun); April 16 - wheat starting to joint (green gun); and June 27 - wheat turned (blue gun). Wheat fields are generally yellow in this image. Figure 2.6f is a mid-season image comprised of acquisitions for March 10 (red gun); April 16 (green gun); and May 4 - wheat jointing (blue gun). Wheat fields are white (three vegetated phases) or yellow (early turned fields-non-green vegetated phase on third date).

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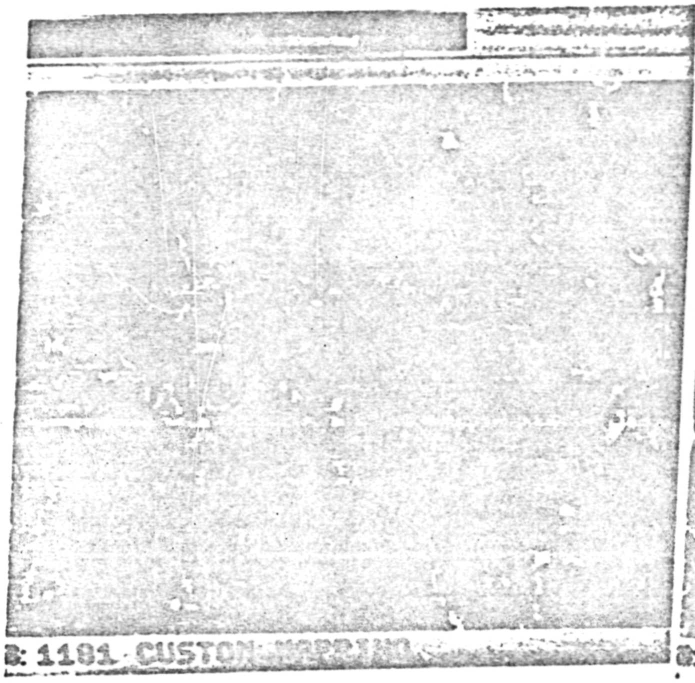
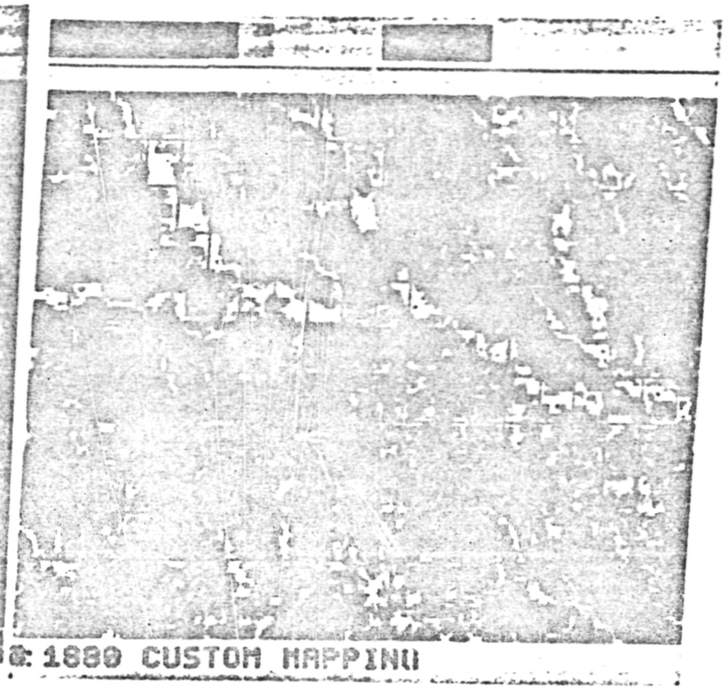
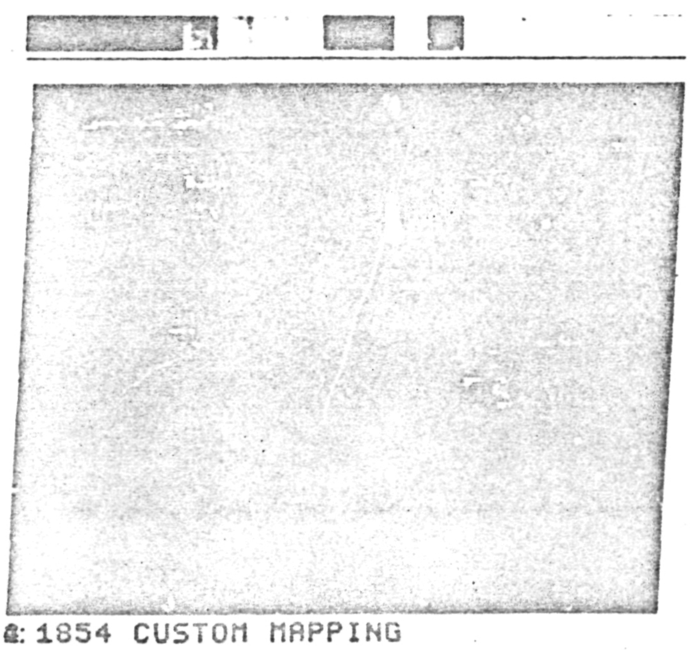


2.6 g



2.6h



2.6i

Figures 2.6g, 2.6h, and 2.6i Kansas segments 1181, 1880, and 1954, respectively. At-harvest multitemporal images for 2x MSS 7/MSS 5 data.

Figure 2.6g red gun - March 10 - wheat greening up

green gun - May 4 - wheat jointed to headed

blue gun - July 14 - wheat harvested

Wheat fields are mostly yellow.

Figure 2.6h red gun - May 6 - wheat jointed to headed

green gun - June 10 - wheat headed to turning

blue gun - July 16 - wheat harvested

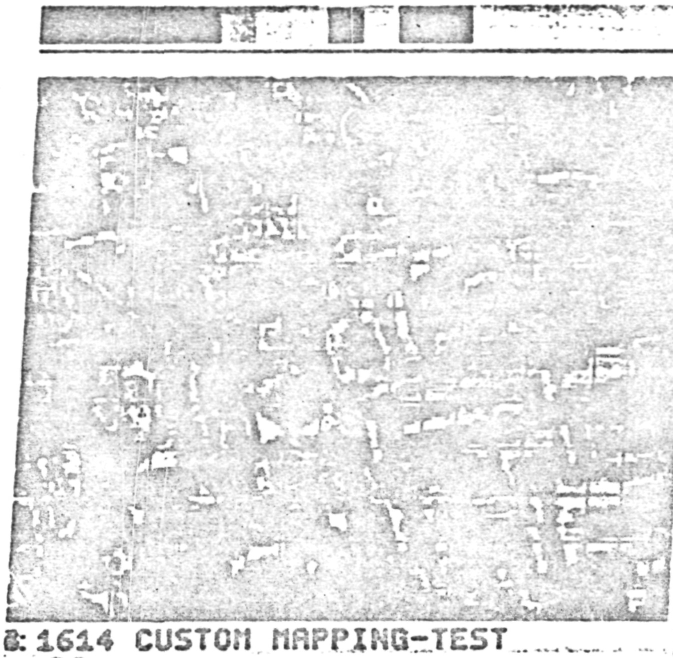
Wheat is mostly red (early turning) or yellow. White is riparian vegetation.

Figure 2.6i red gun - December 15 - wheat planted; some fields emerged, others not

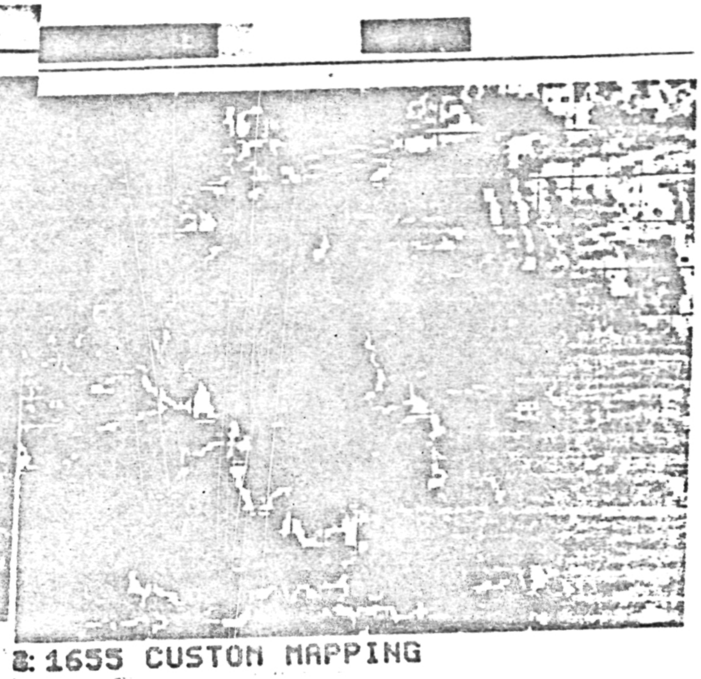
green gun - June 2 - wheat headed

blue gun - July 17 - wheat harvested

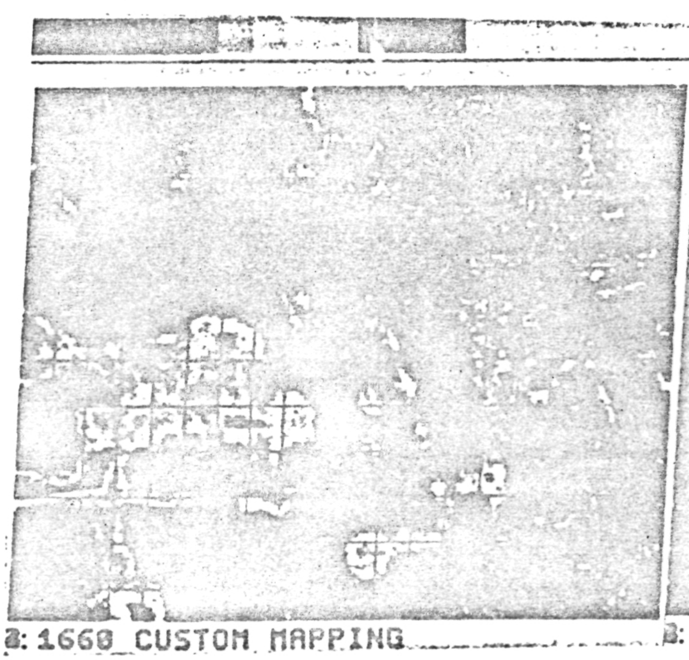
Wheat is generally yellow, with late emerging fields shown in green, and early turning fields in red. Blue fields are summer crops, black fields are fallow as of the July 17 date.



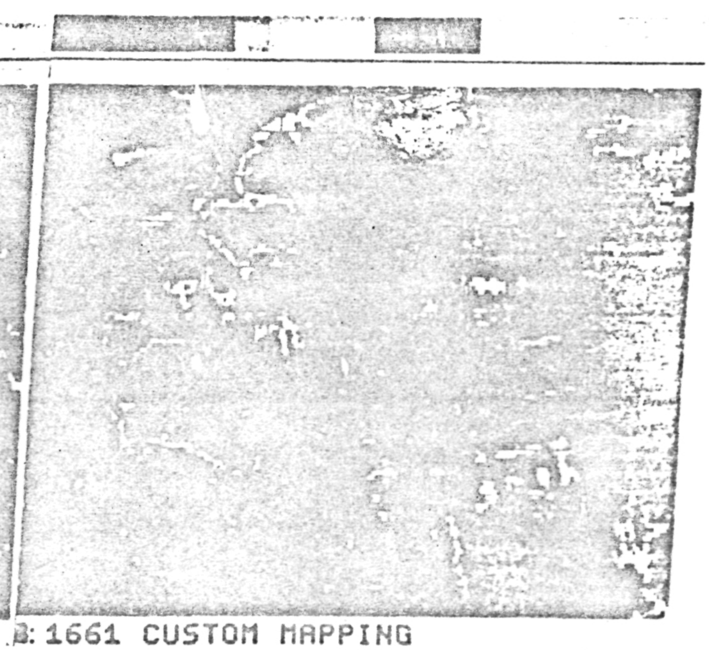
2.6j



2.6k



2.6l



2.6m

Figures 2.6j, 2.6k, 2.6l, and 2.6m North Dakota segments 1614, 1655, 1660, and 1661, respectively. At-harvest multitemporal composite images of 2x MSS 7/MSS 5 ratio data.

Figure 2.6j *red gun - May 8 - some wheat emerged, but much not emerged*

green gun - July 19 - wheat turning

blue gun - August 6 - wheat turned or harvested

Wheat is mostly green in this image with some early emerged fields shown in yellow.

Figure 2.6k *red gun - May 28 - wheat emerged*

green gun - July 20 - wheat headed

blue gun - August 7 - wheat turned or harvested

Wheat colors highly variable in this image due to several fields of differing development.

Figure 2.6l *red gun - May 26 - wheat emerged*

green gun - June 13 - wheat jointed

blue gun - August 6 - wheat turned

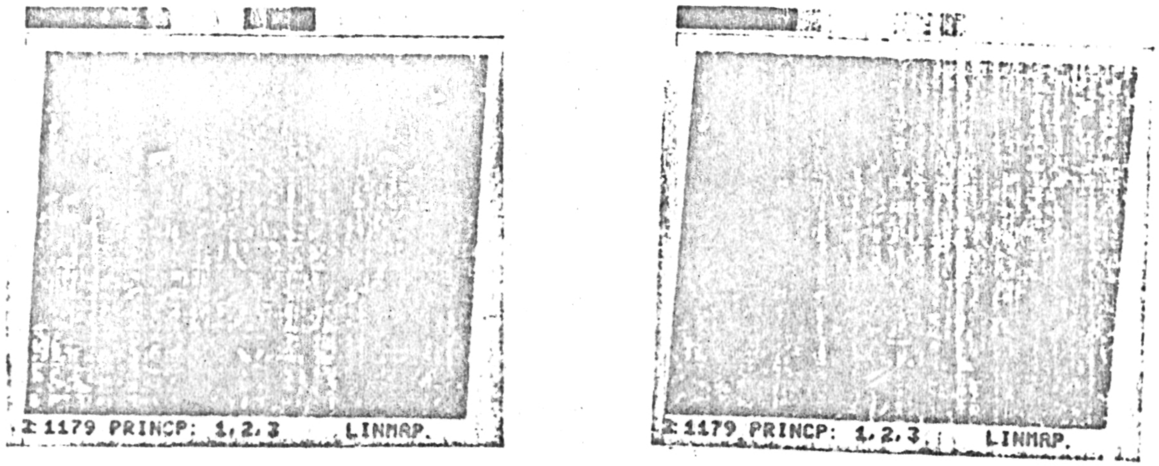
Misregistration makes this image difficult to interpret within the narrow fields.

Figure 2.6m *red gun - July 1 - wheat jointed*

green gun - August 6 - wheat turned

blue gun - August 24 - wheat harvested

Wheat is mostly red, with some late turning fields shown in yellow.



a b

Figure 7 *Example of image products utilizing the 1st, 2nd, and 3rd principle components (assigned to the red, green, and blue guns, respectively) from a principle component analysis on the Tasselled Cap greeness bands (K-2) for four dates. In figure 2.7a, wheat fields tend to be blue or gray green (compare to Figures 2.6a and 2.6b). In figure 2.7b, wheat fields tend to be cyan or yellowish green (compare to Figures 2.6c, 2.6d, 2.6e, and 2.6f). It is very difficult for an analyst to predict the probable color and color variability of wheat fields on these image products. This limits their usefulness for crop type labeling. However, they may be useful in condition assessment once the crop type has been identified from other products.*

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Numeric Product

The second presentation format examined was computer print-out of numeric data. The date specific VI parameter 2x MSS 7/MSS 5 was printed out for four specified acquisitions for a block of pixels 5 points by 5 lines in size, centered on a 10 point by 10 line sample of grid intersections (209 grid points). The actual value of the VI for any given sample pixel could then be referenced for any of the four dates. The 5x5 size was chosen 1) to allow for the misregistration of pixels from date to date; and 2) to provide adequate information for the area surrounding the pixel of interest. Thus the analyst could assess data variability at the point of interpretation. Figure 2.8 illustrates part of the multitemporal block dump for one segment for one grid intersection point. The four dates were selected by the analysts as the four most significant available dates for that segment for the interpretation of wheat.

2.5.2.2 Evaluation of Multitemporal Auxiliary Aid Products

The auxiliary aid products described above were evaluated in terms of ease of use and analyst labeling accuracy. An experimental design was developed for the last of these two criteria. In this design, two auxiliary products were compared to a control procedure. The control procedure consisted of analysts labeling the 209 grid intersections for 17 segments (9 - Kansas, 8 - North Dakota) using the standard PFC product and standard auxiliary data alone. The segments were selected to represent the total range of variability within the two states. Next the 209 segment grid intersections were interpreted using one of the auxiliary products: (1) the 2x MSS7/MSS 5 multitemporal image or (2) the multitemporal numeric block dump of 2x MSS 7/MSS 5 in concert with the standard PFC product and standard ancillary data. Analysts therefore, interpreted the test segments twice, first without an auxiliary product, and second with one of the auxiliary products.

In order to insure that the auxiliary products were sufficiently considered during the test, the analysts were instructed to 1) note the auxiliary image color, or acutal VI value and its interpreted inference, and 2) to allow the auxiliary product to set their expectations prior to checking the standard PFC product for completion of the interpretation.

Paired t-tests were used to evaluate the effect of the auxiliary products on analyst labeling accuracy. The test performance measure was defined as the change in labeling accuracy obtained with the combination of auxiliary and standard PFC product versus use of the standard products alone. These labeling accuracy changes by segment by treatment are the observations entered into the Paired t-tests.

The other auxiliary image products were evaluated qualitatively by comparison among the products. Those products included the multitemporal K-2 images, and the principle component images of multitemporal K-2's.

BLOCKS CENTERED AT (80, 80).

BAND 17 (7/5$10MR)

1.79	1.13	.91	.97	.94
1.38	1.22	.82	.91	1.04
1.04	1.10	.97	.88	.91
.94	.97	1.00	1.10	1.07
.97	.97	1.13	1.16	1.19

BAND 18 (7/5$AP16)

2.08	1.79	1.28	2.08	2.08
1.50	1.68	1.42	.91	.95
1.20	1.31	1.39	.95	1.02
1.09	1.06	1.50	1.20	1.24
1.17	1.13	1.13	1.20	1.24

BAND 19 (7/5$MAY4)

1.31	1.04	.94	.92	.90
1.46	1.17	1.00	.96	1.02
1.17	1.12	.94	.92	.92
1.17	1.17	1.19	1.00	1.04
1.08	1.12	1.25	1.12	1.12

BAND 2 (7/5$JE27)

.92	1.08	1.18	1.08	1.64
1.23	1.33	1.18	1.23	1.48
2.75	1.89	1.58	1.53	2.50
2.14	1.89	1.99	1.89	1.69
2.55	2.91	3.97	2.86	1.58

BLOCKS CENTERED AT (90, 80)

BAND 17 (7/5$10MR)

1.22	1.19	1.04	1.22	1.79
.91	1.13	1.47	1.41	1.41
1.29	1.44	1.51	1.54	1.35
1.63	1.51	1.38	1.35	1.32
1.38	1.54	1.38	1.13	1.04

BAND 18 (7/5$AP16)

1.90	1.64	1.61	1.46	1.46
1.90	1.57	1.50	1.90	2.23
1.72	1.97	2.15	2.81	2.63
2.19	2.26	2.26	1.97	1.72
1.97	1.97	1.97	2.23	1.90

BAND 19 (7/5$MAY4)

1.46	1.58	1.46	1.37	1.46
1.43	1.39	1.33	1.10	1.27
1.33	1.25	1.27	1.50	1.36
1.17	1.39	1.85	1.87	1.68
1.93	1.93	1.93	1.93	1.56

BAND 2 (7/5$JE27)

1.54	1.69	2.14	1.38	.92
1.79	2.09	4.53	2.91	1.23
3.62	4.69	5.60	3.67	1.69
5.09	4.74	4.84	3.36	2.09
4.69	4.58	4.38	2.19	1.38

BLOCKS CENTERED AT (100, 80)

BAND 17 (7/5$10MR)

1. 7	1.19	1.22	1.13	1.22
1.22	1.07	.97	.94	.85
1.51	1.16	.94	.88	.88
1.10	1.07	.91	1.04	1.04
.91	.94	1.13	1.19	1.07

BAND 18 (7/5$AP16)

3.21	2.67	2.23	1.58	1.46
2.56	2.15	1.67	1.06	1.06
1.90	1.68	1.33	1.02	.98
1.31	1.42	1.13	.98	1.02
1.83	1.42	1.20	1.20	1.28

BAND 19 (7/5$MAY4)

1.33	1.46	1.58	1.33	1.35
1.70	1.70	1.52	1.21	1.21
1.64	1.43	1.12	1.02	.92
1.52	1.50	1.27	1.00	1.02
1.21	1.33	1.17	1.06	.96

Figure 2.8 Example of 2x MSS 7/MSS 5 ratio of numeric product tested. Illustrated is the multitemporal 5 points by 5 lines pixel blocks centered on (80, 80; 90, 80; and 100, 80) for segment 1179 for four dates (10 Mar 76, 17 Apr 76, 4 May 76, and 27 Jun 76). The 5x5 block allows the analyst to track mis-registered pixels as well as evaluated variability around the pixel of interest.

2.5.3 RESULTS AND DISCUSSION

2.5.3.1 Analyst Response to Auxiliary Products

Analyst reaction to the 2x MSS 7/MSS 5 auxiliary products tested was mixed. The analysts felt that each product had its good and bad points.

The 2x MSS 7/MSS 5 image product is valuable for gaining a quick impression of the location and overall spatial distribution of probable wheat fields within a segment. The image product also gives the analyst an idea of the variability in wheat development in early-planted versus later-planted fields. At the specific pixel level, however, where the objective is to label a given pixel as wheat or non-wheat, the multitemporal image product cannot provide the precise quantitative information often necessary for accurate point interpretation. First, the exact 2x MSS 7/MSS 5 ratio values cannot be gained from the image; therefore, the analyst must try to estimate these values from the relative hue and saturation of the pixel within the image. In actuality, only the presence or absence of vegetation can be determined. The image is a compression of data from three acquisitions, and, although the dates on which vegetation occurs can be determined from pixel color, it is more difficult to estimate the degree to which the 2x MSS 7/MSS 5 values exceed the soil line on the individual dates. To do so involves a time-consuming consideration of what combination of values from the three acquisitions could lead to the intensity of color observed in the display and is at best an approximation.

A second drawback in working with the 2x MSS 7/MSS 5 image product is misregistration. Pixels on the edge of fields, or within narrow strip fields (common in North Dakota) are often represented by meaningless colors in the multitemporal image display. These colors are a combination of 2x MSS 7/MSS 5 values obtained from different fields on each of the three different dates. The multitemporal image product, therefore, was of little value in the interpretation of edge pixels, since they could not be traced through time using the multitemporal image product.

In contrast to the image product, the 2x MSS 7/MSS 5 numeric block dump does provide the analyst with exact 2x MSS 7/MSS 5 ratio values for specific pixels on specific dates. No "second guessing" is required to determine these values - they can be read directly from the printout. In cases of misregistration the numeric block dump was especially valuable, since the analyst was able to locate the exact pixel even when it did not appear at the grid intersection on non-reference acquisitions. The block dump did not, however, allow for a quick overall impression of wheat and/or small grain distribution as did the multitemporal image product.

Finally, the analysts felt that, while the multitemporal 2x MSS 7/MSS 5 image product and the 2x MSS 7/MSS 5 numeric block dump product were not necessary for the interpretation of each selected pixel in the test segments, there were specific instances when signature on the PFC standard product data was inconclusive, and the auxiliary products were certainly beneficial. It

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was felt that in these cases, the numeric block dump was more helpful than the image product. The numeric block dump provided exact vegetation indicator values which could be directly evaluated as to how green or how close to the soil line a given pixel was on a given date. Of course, there were still problems connected with the precise interpretation of the ratio data, and the numeric dump was not always useful in resolving indecisions regarding the identity of some pixels.

Rather than choose one product as superior to the other, the analysts stressed the importance of making both products available for interpretation. Thus the appropriate product could be consulted when the standard PFC product and conventional ancillary data was insufficient for confident interpretation of the data.

2.5.3.2 Results of Paired t-Tests

Analyst labeling accuracies for the seventeen test segments are presented in Tables 2.24 and 2.25 for wheat in Kansas and small grains in North Dakota, respectively.

The average (9 segments) omission error for wheat in Kansas for the control treatment, treatment #1 (2x MSS 7/MSS 5 image) and treatment #2 (2x MSS 7/MSS 5 numeric block dump) was 20.5% (σ = 12.6%), 22.0% (σ = 10.8%) and 24.4% (σ = 16.5%), respectively. The average commission error for wheat in Kansas was similarly 10.2% (σ = 7.8%), 13.9% (σ = 10.5%), and 12.2% (σ = 6.7%). In North Dakota the average (8 segments) omission error for small grains for the control treatment, treatment #1, and treatment #2 were 25.8% (σ = 10.0%), 25.7% (σ = 10.3%), and 23.5% (σ = 8.0%), respectively. Similarly, the commission error for small grains was 18.5% (σ = 13.9%), 23.4% (σ = 24.9%), and 18.8% (σ = 11.8%). In Kansas, Paired t-tests (Table 2.26) indicated that there was a significant increase in omission error (at the 10% level) and commission error (at the 5% level) for treatment #1 (MSS 7/MSS 5 image). The results for treatment #2 (MSS 7/MSS 5 numeric product) in Kansas show similar trends although the differences are not significant.

In North Dakota none of the differences between treatment #1 and control, and treatment #2 and control are significant. There was, however, a slight tendency for increased commission error with both treatment #1 and treatment #2. This tendency was not as pronounced as in the Kansas segments. The omission errors for treatment #1 and treatment #2 in North Dakota showed opposite trends for each treatment. A slight increase in omission error for treatment #1 was observed, but again not as pronounced as in the Kansas segments. The omission error for treatment #2, however, did show a definite decreased tendency, though not significantly within these limited tests.

While the Kansas results for treatment #1 were the only statistically significant results, there was a consistent tendency in both states to increase commission error with both treatment #1 and treatment #2. Likewise, while not significant except for Kansas treatment #1, there was a tendency to increase omission error for both test treatments except for treatment #2 in North Dakota where an opposite trend was indicated. The tendency for increased omission error for treatment #1 (the image product) may be a function of misregistration with multitemporally compressed data. Analysts interviewed indicated dissatisfaction with the image

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Table 2.24 Analyst Labeling Accuracy for Wheat in Kansas

		CONTROL		TREATMENT 1		TREATMENT 2	
Seg #	% Corr Total	% Corr	% Comm	% Corr	% Comm	% Corr	% Comm
1172	90.6	84.0	10.6	85.9	6.3	-----	-----
	91.8	89.5	9.5	-----	-----	86.3	8.3
	90.6	86.0	10.4				
1179	87.8	65.1	26.3	68.9	31.1	-----	-----
	92.3	77.6	11.6	-----	-----	-----	-----
	92.2	76.7	15.4	-----	-----	47.6	16.7
1181	85.1	63.9	9.8	-----	-----	55.2	13.9
	90.9	76.5	5.4	-----	-----	-----	-----
	88.5	67.6	2.0	73.1	12.3	-----	-----
1851	95.7	89.8	5.4	-----	-----	86.0	5.8
	94.3	84.5	5.8	-----	-----	-----	-----
	97.6	93.2	1.8	91.4	8.6	-----	-----
1854	93.6	86.7	2.7	-----	-----	-----	-----
	96.1	93.8	3.8	-----	-----	90.7	8.1
	94.1	89.6	5.5	92.2	4.1	-----	-----
1857	93.7	90.3	11.1	-----	-----	-----	-----
	96.6	93.4	5.0	80.9	12.1	-----	-----
	97.1	95.1	4.9	-----	-----	86.9	5.4
1880	87.6	52.3	11.5	-----	-----	-----	-----
	87.6	56.5	13.3	-----	-----	72.7	11.1
	93.8	71.4	0.0	62.8	3.6	-----	-----
1894	90.3	89.0	11.0	81.9	16.1	-----	-----
	88.9	83.5	9.5	-----	-----	-----	-----
	93.7	90.6	6.1	-----	-----	91.5	13.8
1891	79.9	71.4	23.6	-----	-----	-----	-----
	78.4	70.7	29.3	66.2	31.1	-----	-----
	77.5	58.7	25.4	-----	-----	63.6	26.9
AVERAGE:	90.4	79.5	10.2				
AVERAGE ERROR:	9.4	20.5	10.2	22.0	13.9	24.4	12.2
STANDARD DEVIATION:	5.4	12.6	7.8	10.8	10.5	16.5	6.7

Table 2.25 Analyst Labeling Accuracy for Small Grains in North Dakota

Seg #	% Corr Total	CONTROL % Corr	CONTROL % Comm	TREATMENT 1 % Corr	TREATMENT 1 % Comm	TREATMENT 2 % Corr	TREATMENT 2 % Comm
1614	79.9	73.8	22.6	-----	-----	69.7	38.7
	84.2	72.6	16.4	56.0	20.3	-----	-----
	78.5	58.5	18.6	-----	-----	-----	-----
1642	91.8	81.6	2.4	68.5	3.3	-----	-----
	83.6	81.1	6.7	-----	-----	76.5	2.8
	86.5	79.3	0.0	-----	-----	-----	-----
1648	84.1	71.6	25.9	-----	-----	82.5	16.1
	87.4	74.3	11.9	88.4	3.8	-----	-----
	87.2	62.7	7.3	-----	-----	-----	-----
1651	87.0	75.4	18.3	75.0	2.2	-----	-----
	94.2	87.1	4.7	-----	-----	-----	-----
	95.7	88.4	1.6	-----	-----	92.8	9.9
1655	71.1	42.3	37.5	-----	-----	72.6	10.0
	80.9	67.1	27.4	-----	-----	-----	-----
	90.1	76.1	7.2	83.3	8.3	-----	-----
1656	92.3	75.0	50.0	-----	-----	-----	-----
	92.8	81.2	48.0	87.5	72.0	-----	-----
	98.1	81.2	7.1	-----	-----	66.7	16.6
1660	80.7	67.1	22.7	-----	-----	73.0	32.5
	82.6	73.8	30.8	76.7	18.8	-----	-----
	88.4	78.5	10.1	-----	-----	-----	-----
1661	79.1	74.3	29.5	73.4	38.9	-----	-----
	81.3	77.2	24.7	-----	-----	75.7	26.4
	86.1	73.0	12.9	-----	-----	-----	-----
AVERAGE:	86.0	73.9	18.5				
AVERAGE ERROR:	14.0	26.1	18.5	23.9	21.0	23.8	19.1
STANDARD DEVIATION:	6.3	9.6	13.9	10.7	24.1	8.2	12.3

TABLE 2.26 RESULTS OF PAIRED t TEST

SUBTASK C: EXPLORATION OF MULTITEMPORAL DATA COMPRESSION PRODUCTS

		AVE. ERROR	$s_{\bar{d}}$	t	dF	SIGNIFICANCE LEVEL
TREATMENT 1: MULTITEMPORAL 7/5 RATIO IMAGE						
KANSAS:	% CORRECT WHEAT - P(W/W)	-3.40	1.80	-1.387	8	10%
	% COMMISSION ERROR - P(W/N)	3.38	1.33	2.54	8	5%
NORTH DAKOTA:	% CORRECT SM GR - P(SG/SG)	-.69	3.73	-.185	7	N.S.
	% COMM ERROR - P(SG/N)	.38	4.53	.083	7	N.S.
TREATMENT 2: NUMERIC 5x5 BLOCKS OF 7/5 RATIOS						
KANSAS:	% CORRECT WHEAT - P(W/W)	-3.79	4.05	-.935	8	N.S.
	% COMMISSION ERROR - P(W/N)	1.82	1.02	1.781	8	N.S. (~15%)
NORTH DAKOTA:	% CORRECT SM GR - P(SG/SG)	3.66	4.68	.783	7	N.S.
	% COMM ERROR - P(SG/N)	.19	4.84	.038	7	N.S.

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product due to the misregistration problem as well as the lack of discrete information for each acquisition date due to the composite nature of the data compression product.

For treatment #2 (numeric product) the tendency for increased omission error in Kansas and decreased omission error in North Dakota probably indicates the need for the development of additional consistent interpretation guidelines for the analyst.

Experience with similiar kinds of test situations involving analyst interpretations has shown that analyst variability within a large pool of temporary type analysts is usually so large as to mask any possible differences between treatments being tested. Thus an attempt was made to minimize variability due to analyst effect. Analysts selected to participate in the tests were chosen based on similar levels of experience and ability. Paired t-tests applied to analyst labeling accuracies for the control treatment for all possible pairs of analysts by segment indicated that a significant difference (10% level) did exist between the results of analyst 1 and 2. No significant difference was indicated, however, between the results of analyst 1 and 3, or 2 and 3. While the above analyses show that the variability among all test analysts could not be dismissed as insignificant, it was probably minimized as much as could reasonably be expected.

2.5.3.3 CONCLUSIONS FROM QUALITATIVE COMPARISON OF IMAGE PRODUCTS

From a qualitative comparison of multitemporal 2x MSS 7/MSS 5 composite images and multitemporal K-2 composite images (Figure 2.6, a-b, c-d, e-f), the conclusion was drawn that both VI's (2x MSS 7/MSS 5 and K-2 Tasselled Cap green number) performed equally well in multitemporal composite images. Lack of ability to more consistently place the soil line decision boundary within the K-2 data limits the usefulness of this data at present. Thus, with the current state of procedures for using 2x MSS 7/MSS 5 ratio data and Tasselled Cap green number data, both are equally useful in composite image products.

Image products from principle component analysis of multitemporal K-2 data are very difficult to quickly interpret. The analyst cannot predict the resultant colors for wheat or any other ground condition let alone the variability in color representation for any ground condition. To use these image products the analyst must "train" himself with the standard PFC product and ancillary data. The product is very sensitive to the particular data set (i.e. segment and acquisitions) for which it is produced, such that the analyst must retrain himself for each principle component image. Thus the usefulness of this procedure for the production of auxiliary aid interpretation products appears limited at this point. Further exploration and development of this product and similaryly produced images may lead to the discovery of situations and procedures whereby these type of image products could be useful, but at present the analyst can extract little useful information from them.

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APPENDIX A

APPENDIX A: LEGEND CODE FOR SIGNATURE EXTENSION LAND USE/SOIL ASSOCIATION STRATA

The land use/soil association strata are annotated with a fractional code. The numerator is the land use designation and the denominator is the soil association - soil subgroup designation.

land use code   crop diversity code

211-1
88-A ---soil association - soil subgroup code

APPENDIX A.1: LAND USE CLASSIFICATION CODE

100 - Urban and Built-up Land

- *110 - Residential, commercial, industrial, institutional, transportational, mixed, open and other.*
- *120 - Strip and clustered settlements.*
- *130 - Resorts*

200 - Agricultural Land (more than 15% of area is cultivated)

- *211 - Cropland and intensive pasture (more than 75% of the area is cultivated)*
- *212 - Cropland and intensive pasture (more than 50% but less than 75% of the area is cultivated)*
- *213 - Orchard and vineyards*
- *220 - Extensive agriculture (less than 50% of the area is cultivated)*

300 - Rangeland (less than 15% of the area is cultivated)

- *310 - Grassland range*
- *320 - Woodland range*
- *330 - Chaparral range*
- *340 - Desert shrub range*

400 - Forest Land

500 - Water

600 - Non-forested Wetland

700 - Barren Land

800 - Tundra

900 - Permanent Snow and Icefields

APPENDIX A.2: CROP DIVERSITY CODE

-1: Relatively high crop diversity

-2: Medium crop diversity

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-3: Low crop diversity

APPENDIX A.3. SOIL ASSOCIATION/SOIL SUBGROUP CODE

Udic Ustolls and Aquolls, Mesic

50: Argiustolls; level-rolling; clayey and fine silty.

50-A: Crete[65*] - Geary[25] Association (Rice Co.): Deep, nearly level to moderately sloping soils that formed in loess; on uplands. (Parent material: Sanborn Fm. including Loveland and Peoria silt members.)
Minor soils: Clark, Tabler and Hobbs soils.

50-B: Smolan[48] - Crete[34] - Hobbs[8] Association (Rice Co.): Deep, moderately sloping to nearly level soils that formed in loess and medium-textured alluvium; on uplands and narrow flood plains.
Minor soils: Geary, Clark, Lancaster and Hedville soils.

50-C: Crete[50] - Ladysmith[20] Association (Harvey Co.): Deep, nearly level to gently sloping, moderately well-drained silt loams and silty clay loams on uplands.
Minor soils: Smolan, Farnum, Hobbs and Detroit soils.

Bethany-Tabler Association[90] (Reno Co.): Deep, dark, nearly level to gently sloping, loamy soils that have clayey subsoils.
Minor soils: Smolan and Vanoss soils.

50-D: Ebenezer, Berg, Lancaster, Westfall Association (Saline Co.): Deep, moderately sloping, moderately well drained to well drained silt loams and silty clay loams, developed on calcareous loess; on uplands.

50-E: Elmo, Lockhard, Berg Association (Saline Co.): Deep, level to gently sloping, well drained, silt loams and silty clay loams, developed on wind blown deposits of loess and mixtures of loess and outwash from Cretaceous shales and sandstoned; on uplands.

*Superscripts refer to the percentage of a given association within a specific county occupied by the particular soil series.

50-F: Hastings - Crete - Geary Association (Republic Co.); Sloping-rolling, deep soils developed in loess and mixed materials.
Minor soils: Kenesaw, Kipson and Muir soils.

50-G: Crete - Butler - Hastings Association (Republic Co.): Nearly level - undulating, deep soils developed in loess.
Minor soils: Geary, Kipson, and Hobbs soils.

50-H: (Jewel and Mitchell Co.)

53: Argiustolls - Haplustolls: level-steep; clayey-skeletal, clayey and loamy; lithic.

53-A: Labette[26] - Florence[21] Association (Morris Co.): Moderately deep, gently sloping to sloping soils that have a clayey subsoil; and deep, sloping to moderately steep cherty soils that have a cherty clay subsoil; on uplands.
Minor soils: Tully [16], Dwight[15], Irwin, Clime, Sogn and Reading soils and areas of alluvial land.

53-B: Irwin[50] - (Kipson - Sogn)[30] - Ladysmith Association (Morris Co.): Deep, nearly level to gently sloping and sloping soils that have a clayey subsoil, and shallow, gently sloping to moderately steep soils that are loamy throughout; on uplands.
Minor soils: Tully[8], Labette[12], and Dwight [12] soils.

53-C: Crete Association (Geary Co.): Nearly level to steep.
Minor soils: Sogn--native grass, steep slopes, Irwin, Hobbs, Geary, and Hastings soils.

54: Argiustolls - Haplustolls: lithic, loamy, undulating-hilly; clayey, fine-loamy and fine silty.

54-A: Hedville[40] - Lancaster[30] - Smolan[15] Association (Rice Co.): Shallow, moderately deep, and deep, gently sloping to moderately steep soils that formed in material derived from sandstone, sandy shale, and loess; on uplands.
Minor soils: Geary, Hobbs, Crete and Kipson soils. (Parent material: Dakota Fm., Greenhorn limestone, Graneros shale.)

54-B: Kipson- Tully - Crete Association (Republic Co.): Rolling, deep and shallow soils developed in loess and limestone - shale materials.
Minor soils: Hastings, Lancaster and Muir soils.

S4-C: (Washginton Co.):
Parent material: Wellington formation - gray shale and limestone.

S4-D: (Ottowa and Cloud Co.):
Parent material: Eolian silt and glacial pleistocene terrace deposits.

S5: Argiustolls - Natrustolls: level-undulating; clayey.

S5-A: Irwin[51] - Ladysmith[26] Association (Morris and Butler Co.): Deep, nearly level to sloping soils that have a silty clay loam surface; silty, clayey subsoil; on uplands.
Minor soils [23]: Alluvial land, Reading, Labette, Dwight, Sogn, and Verdigris soils.

S5-B: Elmo, Kipson, Berg, Smolan, Idana Association (Saline Co.): Very shallow (Kipson) to deep, excessively drained (Kipson) to well drained, silt loams and silty clay loams; on uplands.

S5-C: Dwight[40] - Labette[40] Association (Butler Co.): Nearly level to sloping, moderately deep soils that have a silt loam or silty clay loam surface layer and a silty clay subsoil; on uplands.
Minor soils: Irwin and Sogn soils.

S5-D: Irwin[35] - Rosehill[30] - Clime Association (Harvey Co.): Deep and moderately deep, gently sloping to sloping, well-drained silty clay loams and silty clays on uplands.
Minor soils: Hobbs, Ladysmith, and Goessel soils, and Breaks-Alluvial land complex.

S6: Argiustolls - Pellusterts - Haplustolls: level-undulating; clayey.

S6-A: Ladysmith[80] - Goessel[15] Association (Harvey Co.): Deep, nearly level to gently sloping, moderately well drained silty clay loams and silty clays on uplands.
Minor soils: Farnum and Naron soils and Breaks-Alluvial land.

S6-B: (Marion Co.)

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Typic Ustolls and Aquolls, Mesic

65: Argiustolls: level-undulating; clayey.

65-A: Clayey Soils of the High Plains Tableland:

Spearville-Harney Association (Finney Co.): Nearly level and gently sloping, deep, clayey soils, that are well drained and formed in silty loess.
Minor Soils: Richfield and Randall soils.

Spearville-Harney Association (Gray Co.): Nearly level and slightly concave deep, clayey soils of the High Plains tablelands.
Minor Soils: Randall soils.

Harney[73] Association (Hodgeman Co.): Deep, nearly level to gently sloping well-drained, loamy soils on uplands.
Minor Soils: Ost, Richfield, Spearville, Uly, Ness, and Penden soils.
(Parent material: loess).

Harney-Spearville Association (Hodgeman Co.): Deep nearly level to gently sloping, well drained to moderately well drained loamy soils on uplands.
Minor Soils: Ness, Penden and Richfield soils.
(Parent material: mainly loess)

Harvey[78] - Spearville[8] - Ulysses[8] Association (Ford Co.): Deep, nearly level and gently sloping, well-drained, loamy and clayey soils.
Minor Soils: Mansic, Mansker[73], Hobbs, Randall, Colby soils and Alluvial land.

65-B: (Barton Co.) (Parent material: recent aluvium)

65-C: Zenda[26] - Hord[22] - (Dale) Waldeck[12] Association (Edwards Co.) Mainly deep, nearly level, somewhat poorly drained and well-drained, loamy soils on bottom lands.
Minor Soils: Canadian, Platte, Lesho, Las Animas, and Tabler soils and slickspots.
(Parent material: recent loamy alluvium)

(Barton Co.) (Parent material-recent alluvium)

Roxbury[61] - Bridgeport[10] Association (Hodgeman Co.): Deep, nearly level, well drained to moderately well drained, loamy soils on low terraces and flood plains.
Minor Soils: Broken alluvial land and Detroit, Hord and Ness soils.

Part of the Dale - Leshara - Las Animas Association (Ford Co.): Nearly level, loamy, alluvial soils that have a fluctuating water table and some saline-alkali spots.
Minor Soils: (Dale, Humbarger, Canadian),[60] (Leshara, Las Animas*, Lincoln*)[29] soils, and (Alluvial land and slickspots)[4].

70: Argiustolls - Haplustolls - Calciustolls: level-rolling; clayey, fine-silty and fine-loamy.

70-A: Soils of the Crooked Creek Drainage Area: Richfield - Ulysses - Mansic Association (Gray and Meade Co.): Nearly level to sloping, deep, loamy soils of the Crooked Creek drainage area.

Ulysses[41] - Mansic[27] - Mansker[1] Association (Ford Co.): Sloping and strongly sloping, calcareous loamy soils.
Minor Soils: Potter[2], Otero, (alluvial land and Hobbs)[7], Colby[5], Harney[3] and Bippus[3] soils.

70-B: Soils of the Dissected Uplands of the Pawnee River Drainage Basin:

Harney[63] - Penden[21] Association (Hodgeman Co.): Deep, nearly level to sloping, well-drained loamy soils on uplands.
Minor Soils: Uly, Ness, Roxbury, and Bridgeport soils.
(Parent material: Harney-loess, Penden-calcareous clay loam outwash).

Harney[37] - Penden[34] - Bridgeport[3] Association (Hodgeman Co. and Ness Co.): Deep, nearly level to sloping well-drained, loamy soils on uplands.
Minor Soils: Coly, Kim, Uly, Wakeen and Richfield soils.
(Parent material: Bridgeport-calcareous silty alluvium)

70-C: (Ellis Co.) (Parent material: Crete & Loveland Fm. underlain by Sappa and Grand Island Fm.)

70-D: Campus[35] - Harney[20] - Carlson[12] Association (Ellis and Trego Co.): Moderately deep and deep, nearly level to moderately steep, well-drained soils that have a loam to silty clay subsoil or substratum; on uplands.
Minor Soils: Armo, Canlon, Penden and Mento soils; Rough broken land, alluvial land, and Roxbury-silt loam.

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*Sandier soils, the rest are silt loams and clay loams.

70-E: Harney^{67} - Uly^{10} Association (Edwards Co. and Rush Co.): Deep, gently sloping to sloping, well-drained, loamy soils on uplands.
Minor soils: Breaks and Alluvial land, Campus, Canlon, Tobin, and Holdridge Soils. (Parent material: Carlile Shale.)

70-F: Harney^{43} - Wakeen^{18} - Nibson^{17} Association (Ellis and Rush Co.): Deep to shallow, nearly level to strongly sloping, well-drained and somewhat excessively drained soils that have a silty clay loam and silty clay subsoil; on uplands.
Minor soils: Armo, Mento soils, Hilly land, and Roxbury silt loam .
(Parent material: Harney-loess, Wakeen and Nibson-Carlile interbedded limestone and chalky shale.)

70-G: (Ellsworth Co.) (Parent material: Sappa and Grand Island Fm.)

70-H: (Barton Co.) (Parent material: Dakota Fm., Greenhorn limestone, Graneros Shale)

70-I: Harney^{66} - Carlson^{14} - Armo^{13} Association (Ellis Co.): Deep, nearly level to strongly sloping, well-drained soils that have a clay loam to silty clay subsoil; on uplands.
Minor Soils: Roxbury silt loam and Hord silt loam.
(Parent Material: Crete and Loveland, Peoria Fm.)

70-J: (Gove Co.)

70-K: (Gove Co.)

70-L: (Gove Co.)

70-M: (Ness Co.)

70-N: (Graham and Sheridan Co.)

70-O: (Osborne Co.)

70-P: (Graham Co.)

70-Q: (Graham and Rooks Co.)

70-R: (Russell Co.)

72: Arguistolls - Haplustolls - Ustorthents: level to rolling; fine-silty.

72-A: (Decatur and Norton Cos.)

72-B: (Decatur and Norton Cos.)

72-C: (Norton Co.)

72-D: Geary[35] - Holdridge[25] - Kipson[12] Association (Webster Co., Neb.): Gently sloping to steep, deep silty soils, formed in loess, and shallow, silty soils formed in material derived from chalky limestone; on uplands.
Minor soils: Coly, Hobbs, and Wakeen soils.

72-E: Crete - Geary Association. (Phillips - Smith Co.)
(See 50-A)
Parent material: Sanborn formation.

72-F: (Smith and Jewell Co.)

72-G: (Smith and Jewell Co.)

75: Calciustolls - Argiustolls - Haplustolls: undulating-hilly; loamy and clayey; shallow.

75-A: Soils of the Pawnee River Drainage Basin:

Harney[37] - Penden[34] - Bridgeport[3] Association (Hodgeman Co.): Deep, nearly level to sloping, well-drained, loamy soils on uplands.
Minor soils: Coly, Kim, Uly, Wakeen and Richfield soils.)
(Parent material: Bridgeport-calcareous silty alluvium)

Penden[26] - Campus[24] - Canlon[13] Association (Hodgeman Co.): Deep to shallow, gently sloping to steep well-drained to somewhat excessively drained, loamy calcareous soils, on uplands.
Minor soils: Kipson, Wakeen, Roxbury, Bridgeport, and Harney soils.
(Parent material: Campus - Highly calcareous semi-consolidated caliche; Canlon-semi-consolidated caliche)

(Ness Co.)

Penden[35] - Richfield[28] - Ulysses[18] Association (Lane Co.): Deep, nearly level to strongly sloping, well-drained clay loams and silt loams along drainage ways in the uplands.
Minor soils: Bridgeport, Grigston, Roxbury, Alluvial land, Harney, Keith, Kim, Colby, Campus, Canlon, Badlands and Ness soils.

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75-B: (Clark Co.) (Mansker)
(Comanche Co.)
(Kiowa Co.)

75-C: (Russell, Rush, Lincoln Co.) (Parent material: Dakota Fm., Greenhorn limestone, and Graneros shale.)

75-D: Armo[46] Bogue[19] Heizer[10] Association (Ellis Co.): Deep to shallow, gently sloping to moderately steep, well-drained and moderately well drained soils that have a channery loam to clay subsoil or substratum; on uplands.
Minor Soils: Clay Alluvial land, Hilly land, Brownell, Corinth, Harney, Mento, New Cambria, Roxbury, and Wakeen soils. (Parent material: clay shale.)

75-E: Corinth[71] - Harney[17] Association (Ellis Co.): Moderately deep and deep, nearly level to strongly sloping, well-drained soils that have a silty clay loam to silty clay subsoil, on uplands.
Minor Soils: Bogue, Nibson and Roxbury soils (Parent Material: Corinth-calcareous shale.)

(Russell Co.)

75-F: Mento-Brownell-Wakeen Association (Ellis Co.): Deep and moderately deep, nearly level to strongly sloping, well-drained soils that have a very gravelly loam to silty clay loam subsoil: on uplands.
Minor soils: Alluvial land, Armo, Bogue, Corinth, Harney, Heizer, and Roxbury soils.
(Parent material: Bedded chalky shale and chalk)

(Trego and Graham Co.)

75-G: Armo - Bogue - Heizer Association (Trego and Ellis Co.): Deep to shallow, gently sloping to moderately steep, well-drained and moderately well drained soils that have a channery loam to clay subsoil or substratum; on uplands.
Minor soils: Alluvial land, clayey; Hilly land; Brownell, Corinth, Harney, Mento, New Cambria, Roxbury, and Wakeen soils.

(Norton and Graham Cos.)

75-H: Mento-Brownell-Wakeen Association (Trego and Ellis Co.): Deep to moderately deep, nearly level to strongly sloping, well-drained soils that have a very gravelly loam to silty clay loam subsoil; on uplands.
Minor Soils: Alluvial land, wet; and Armo, Bogue, Corinth, Harney, Heizer, and Roxbury soils.

79-I: Ulysses[34] - Penden[18] - Minnequa[13] Association (Lane Co. and Ness Co.): Deep and moderately deep, nearly level to strongly sloping, well-drained silt loams and clay loams in the rolling uplands.
Minor soils: Richfield, Alluvial land, Bridgeport, Grigston, Badlands, Elkoder, Keith, Harney, Kim, Colby, Canlon and Campus soils.

Colby-Mansker-Potter Association (Scott Co.): Deep, moderately deep, and shallow loamy soils, gently sloping to steep; on uplands.
Minor soils: Bridgeport, and Alluvial land, Badlands, Richfield and Ulysses soils.

Aridic Ustolls, Ustalfs, and Torriorthents, Mesic

88: Argiustolls - Haplustoll: level-undulating; fine-silty and clayey.

88-A: Soils of the High Plains Tablelands:

Richfield-Ulysses-Colby Association (Hamilton Co.): Nearly level to gently sloping, deep, fine silty and clayey loams, on uplands.
Minor Soils: Vona, Otero, Manter, and Goshen soils.

Richfield - Ulysses Association (Kearny Co.): Minor Soils: Colby, Goshen, Manter, Mansic and Lofton soils.

Richfield - Ulysses Association (Finney Co.):
Minor Soils: Manter, Otero, Keith, Randall soils.

Richfield - Ulysses Association (Stanton Co.): Minor
Minor Soils: Lofton soils.

Manter - Dalhart - Ulysses Association (Stanton Co.): Sandy lands.
Minor Soils: Tivoli.

Ulysses - Colby Association (Stanton Co.): Sloping Hardlands.
Minor Soils: Travissilla and Mansker soils.

Ulysses - Richfield Association (Grant Co.): Deep, nearly level to gently sloping, well-drained, silty soils in the uplands.
Minor Soils: Satanta, Colby and Lofton soils.

Richfield - Ulysses Association (Haskell Co.): Deep, nearly level to gently sloping, loamy soils of the High Plains.
Minor Soils: Lubbock, Lofton and Randall soils.

Richfield^{38} - Ulysses^{52} Association (Morton Co.): Loamy soil on uplands.
Minor Soils: Colby, Goshen, Otero and Manter soils.

Richfield - Ulysses Association (Stevens Co.): Silty Hardlands.

Richfield - Ulysses Association (Greeley Co.):
Minor Soils: Colby, Lofton and Goshen soils.

Richfield^{80} - Ulysses^{20} Association (Wichita Co.): Deep, nearly level, loamy soils of the High Plains.
Minor Soils: Lofton soils.

Richfield - Ulysses Association (Scott Co.): Loamy soils on tablelands.
Minor Soils: Randall, Colby, Goshen, Keith, Lubbock, Manter and Tivoli soils.

Richfield - Harney - Ulysses Association (Lane Co.): Deep, nearly level to gently sloping, well-drained silt loams in the uplands.
Minor Soils: Ness, Grigston, Roxbury, Colby, Keith soils.

Goshen - Ulysses Association (Kearny Co.): Soils of the High Plains Drainage ways.
Minor Soils: Otero, Richfield - Mansic Complex, Colby, Lofton, and Manter soils.

88B: Soils of the High Plains:

Spearville - Richfield Association (Gray Co.): Nearly level, deep, clayey and loamy soils of the high plains tablelands.
Minor Soils: Harney and Randall soils.

Richfield^{60} - Spearville^{20} - Ulysses^{15} Association (Haskell Co.): Deep, nearly level, loamy soils that are on the high plains and have a loamy or clayey subsoil.
Minor Soils: Colby, Lofton, and Randall soils.

88-C: Keith - Ulysses Association (Logan Co.): Nearly level and gently sloping soils of loessal tableland.

Keith^{62} - Ulysses^{35} Association (Sherman Co.): Deep, well-drained nearly level and gently sloping silt loams on uplands.
Minor Soils: Richfield, Goshen and Pleasant soils.

88-D: Keith[37] - Ulysses[35] - Goshen[15] Association (Sherman Co.): Deep, well drained, nearly level to sloping silt loams on uplands and in swales.
Minor Soils: Colby and Pleasant soils.

93: Arguistolls - Haplustolls - Torriorthents: Level-rolling; fine silty

93-A: (Gove Co.)

93-B: (Decatur Co.) (Includes Keith - Goshen - Colby soils).

93-C: Keith[82] - Goshen[17] - Colby Association. (Hitchcock Co., Nebraska, and Rawlins Co., Kansas)

Keith[82] - Goshen[17] Association: Silty soils on tablelands. Nearly level to gently sloping soils on uplands.
Minor Soils: Mord and Scott soils.

Colby[74] Association: Silty soils on canyon walls and hills. Gently sloping to steep soils in canyons and on hills along drainage ways.
Minor Soils: Ulysses[14] soils and Rough Broken land[12].

93-D: Keith - Colby Association (Rawlins Co.)

93-E: Colby[35] Association: (Dundy Co., Nebrasks, and Cheyenne and Rawlins Cos., Kansas) Silty soils of loess hills and canyons.
Minor Soils: Rough Broken land[25]; Ulysses[14] and Keith[1] soils.

93-F: (Decatur Co.) (Includes Keith and Colby soils)

93- (Decatur Co.)

95: Argiustolls - Haplustolls - Torripsamments: Undulating-rolling; fine-loamy, coarse-loamy and sandy.

95-A: Anselmo - Keith Association (Dundy Co., Nebraska and Cheyenne Co., Kansas): Sandy soils, silty soils, and sandcaliche woils of upland valleys and hills.
Minor Soils: Dunday, Valentine, Goshen, Ulysses, and Colby soils.

96: Argiustolls - Natrustalfs - Pellusterts: Level-undulating; coarse-loamy and clayey.

96.A: Soils of the Scott-Finney Depression:

Ulysses - Saline Richfield - Saline Drummond Association (Finney Co.): Level to undulating; coase loamy and clayey.
Minor Soils: Saline Church and Colby soils.

Lubbock^{50} - Church - Randall Association (Scott Co.): Deep, clayey soils on benches in the broad, slight depressions of the uplands.

102: Haplustolls - Torriorthents: undulating-hilly; fine-silty.

102-A: Sloping Soils of the High Plains:

Colby - Ulysses Association (Hamilton Co.):
Minor Soils: Potter and Goshen soils.

Colby - Ulysses Association (Kearny Co.):
Minor Soils: Otero, Lincoln, Tivoli, Vona Potter and Goshen soils.

Ulysses - Colby - Bridgeport Association (Stanton Co.): Sloping hard lands and nearly level alluvial lands.
Minor Soils: Goshen soils.

Ulysses^{30} - Colby^{30} - Bridgeport^{25} Association (Grant Co.): Deep, nearly level to sloping, well-drained silty and loamy soils on terraces and in the uplands.
Minor Soils: Humbarger, Glenberg, Bayard, Otero and Goshen soils.

Ulysses - Colby Association (Greeley Co.): Gently to steeply sloping.
Minor Soils: Goshen, Potter, Mansker, Manter and Lincoln soils.

Ulysses^{50} - Goshen^{15} - (Potter - Mansker complex)^{10} Association (Wichita Co.): Deep to shallow, gently sloping to steep, loamy soils in swales and along drainage ways.
Minor Soils: Allubial land, Colby, Bridgeport, Lincoln, Humbarger, Bayard and Manter soils.

Ulysses - Goshen - Colby Association (Wichita Co.): Soils in drainage-ways.
Minor Soils: Bridgeport, Mansker, Potter, Manter, Bayard and Richfield soils.

Ulysses^{50} - Colby^{30} - Goshen^{9} Association (Sherman Co.): Deep, well-drained, nearly level to strongly sloping silt loams on uplands, terraces, and flood plains.
Minor Soils: Bridgeport, Roxbury, Caruso, Alluvial land, Keith and Rough Broken lands.

Ulysses - Colby Association (Logan Co.): Sloping soils of loessal uplands.

102-B: Soils on the Flood Plains and Adjacent Slopes along the Cimarron River:

Otero-Lincoln Association: Soils of the Cimarron River Valley and adjacent slopes (Morton Co.): Potter - Manker Complex[17], Colby[11], Las Animas[4], Otero[25], Lincoln[24], Bridgeport[9].

Colby[35] - Otero[44] - Lincoln[14] Association (Stevens Co.): Cimarron River Valley.

Colby[35] - Otero[30] - Bayard[20] Association (Grant Co.): Deep, gently sloping to sloping, calcareous, loamy soils on fans and in the uplands.
Minor Soils: Lincoln, Manter, Dalhart, Tivoli and Vona soils.

Otero[40] - Colby[30] - Likes[20] Association (Haskell Co.): Deep, gently sloping to strongly sloping, calcareous, sandy and loamy soils in the Valley of the Cimarron River.
Minor Soils: Manter and Glenberg soils.

Colby - Otero - Lincoln Association: Soils on flood plains and adjacent slopes along the Cimarron River.
Minor Soils: Las Animas, Likes, and Bayard soils, and Alluvial land.

102-C: Ulysses[60] - Mansic[30] Association (Wichita Co.): Deep, gently sloping and undulating, loamy soils of the high plains.
Minor Soils: Colby, Lofton, Mansker, and Potter soils

102-D: Lismas - Colby - Gravelly broken land Association (Logan Co.): Soils in broken areas of shale, gravel, and loess along tributaries of the Smoky Hill River.

102-E: Colby - Minnequa - Penrose Association (Logan Co.): Soils of rough broken areas that are crossed by side drains along the south side of Smoky Hill River and Butle Creek.

Penrose - Colby - Loamy Broken Land Association (Logan Co.): Soils in broken areas of chalk rock, sand, and loess along tributaries of the Smoky Hill River.

Bridgeport - Lincoln - Las Animas Association (Logan Co.): Nearly level soils on flood plains and terraces.
Minor Soils: Las, Likes and Volin soils.

102-F: Colby[53] - Rough broken land[25] Association (Dundy Co., Nebraska): Silty soils of loess hills and canyons.
Minor Soils: Ulysses and Keith soils, and Broken Alluvial land.

102-F: (Cont.) Sandy Alluvial Land[30] - Las[20] Association (Dundy Co.): Sandy and loamy soils of River lowalnds.
Minor Soils: Rauville[13] Banks[7], Platte[6], Laurel[4], Las Animas[4], and Elsmere soils.

Bridgeport - Havre Association (Dundy Co., Nebraska): Loamy side of valley-fill foot slopes and high bottom lands.
Minor Soils: Bayard and Glendive soils.

102-G: See 95-A.

104: Paleustalfs - Haplustalfs - Ustipsamments: Undulating-rolling; fine-loamy; coarse-loamy, and sandy.

104-A: Transitional Soils between the Sandhills and High Plains Tablelands:

Vona - Manter - Ulysses Association (Hamilton Co.):
Minor Soils: Otero - Vona complex, Colby silt loams, Goshen silt loams.

Manter - Vona Association (Kearny Co.):
Minor Soils: (Colby and Otero soils.)

Manter - Keith Association (Finney Co.): Sandy and loamy soils between the sandhills and tableland.
Minor Soils: Vona, Otero, and Ulysses soils.

Manter - Satanta Association (Gray Co.): Nearly level and gently undulating loamy soils in areas adjacent to the sandhills.
Minor Soils: Ulysses soils.

Holdridge[97] Association (Ford Co.): Deep, nearly level and gently sloping, well-drained loamy soils on uplands.
Minor Soils: Sandy broken land[3].

Part of the Pratt[49] - Tivoli[29] - Ortello[22] Association (Ford Co.): Nearly level, undulating, or hummocky, deep soils, well-drained to excessively drained on uplands.

Manter - Ulysses - Keith Association(Scott Co.): Sandy and loamy soils, nearly level and undulating areas.
Minor Soils: Tivoli, Dalhart - Richfield complex[2], and Otero soils.

104-B: Soils of the Sandhills and Adjacent Sandy Lands:
Vona - Dahlart - Tivoli Associations: (Haplargids - haplustafs - ustipsamments) nearly level to undulating; rolling to hilly; sandy soils.

Vona - Tivoli Association (Stevens Co.): Sandhills

Dalhart^{65} Association(Stevens Co.): Sandy lands.
Minor Soils: Richfield, Mansic and Otero Soils

104-C: Soils of the Loamy Hardlands: Richfield - Dalhart Association: (argiustolls - haplustalfs) nearly level to gently sloping; silt loams and fine sandy loams.

Richfield^{70} - Dalhart^{30} Association (Stevens Co.)
Hardlands: Loamy .

Richfield - Ulysses Association (Stevens Co.):
Silty Hardlands.

Udic Ustolls, Ustalfs, and Aqualfs, Thermic

133: Paleustolls - Arguistolls - Ustochrepts: Level-rolling; clayey, fine-silty, and fine-loamy.

133-A: Kirkland^{60} - Renfrow^{35} Association (Harper Co.): Deep and moderately deep, nearly level and gently sloping silt loams and clay loams; on uplands.
Minor Soils: Bethany, Pond Creek, and Vernon soils.
(Parent Material: Pleistocene colluvium or pediment deposits.)

133-B: Bethany^{30} - Corbin ^{15} - Tabler^{15} Association (Harper Co.): Deep, nearly level and gently sloping silt loams and clay loams; on uplands.
Minor Soils: Grant, Kirkland, Nashville, Pond Creek and Renfrow soils.
(Parent material: Pleistocene Colluvium and pediment deposits.)

133-C: Vanoss^{90} - Bethany^{10} Association (Reno Co.): Deep, dark, nearly level to moderately sloping loamy soils on wind deposited material.
Minor Soils: Clark soils.

133-D: Renfrow-Vernon Association (Reno Co.): Moderately deep and shallow, reddish soils over clayey shale.
Minor soils: Port soils.

133-E: Farnum - Norge Association (Harper Co.): Deep, nearly level and gently sloping loams, clayey loam subsoil; on uplands.
Minor Soils: Kaski, Shellabarger, and Zavala soils.

Typic Ustolls, Ustalfs, and Ustochrepts, Thermic

134: Argiustolls - Argiaquolls, claycy; level-undulating; fine-loamy and coarse - loamy.

134-A: Farnum[55] - Lubbock[24] Association (Edwards Co.): Deep, nearly level, well-drained, loamy soils on uplands.
Minor Soils: Tabler, Carwile, Ness, and Naron soils.

134-B: Naron[73] Association (Edwards Co.): Deep, nearly level to gently sloping, well-drained and somewhat poorly drained loamy soils on uplands.
Minor Soils: Carwile, Slickspots, Attica, Farnum, and Tabler soils.

134-C: Naron[50] - Farnum[40] Association (Pratt Co.): Nearly level to moderately sloping fine sandy loams and loams that have a subsoil of sandy clay loam or clay loam.
Minor Soils: Carwile, Clark, and Pratt soils.

Farnum[60] - Slickspots[15] - Naron[10] Association (Harvey Co.): Deep, nearly level to gently sloping, well-drained to somewhat poorly drained loams and fine sandy loams on uplands.
Minor Soils: Drummond, Carwille, and Ladysmith soils.

134-D: Bethany[60] - Ost[25] Association (Pratt Co.): Nearly level or gently sloping silt loams to clay, loams with subsoil of clay loam to silty clay.
Minor soil: Tabler, Farnum, Clark, Case, Kaw soils.

134-E: Shellabarger[40] - Albion[35] - Farnum[15] Association (Pratt Co.): Nearly level to strongly sloping sandy loams to loamy, deep and moderately deep, subsoil of sandy clay loam to clay loam, underlain by gravel in places.
Minor Soils: Clark, Ost and Croft soils.

Shellabarger[55] - Farnum[40] Association (Harper Co.): Deep and moderately deep, nearly level to sloping loams and sandy loams; on uplands.
Minor Soils: Albion, Case, Clark and Norge soils.

134-F: Farnum[40] - Ost[30] - Clark[20] Association (Pratt Co.): Nearly level to moderately sloping loams, and nearly level to strongly sloping, calcareous clay loams that have a subsoil of clay loam.
Minor Soils: Shellabarger and Albion soils.

134-F: cont. Nash-Lucien Association (Reno Co.): Moderately deep and shallow, reddish soils over siltstone and soft sandstone.
Minor Soils: Vanoss soils

Clark-Ost Association (Reno Co.): Deep, dark soils over highly calcareous loamy materials.
Minor soils: Bethany soils.

134-G: Carwile^{60} -Tabler^{5} Association (Reno Co.): Deep, dark, nearly level, imperfectly drained soils that have a loamy surface layer and a clayey subsoil.
Minor Soils: Vanoss ^{15}, (Naron, Slickspots, and Farnum)^{20} soils.

134-H: (Commanche Co.)

134-I: (Kingman Co.)

136: Argiustolls - Haplustolls: level-undulating; fine-silty and coarse silty.

136-A: Grant^{35} - Nashville^{25} - Pond Creek^{25} Association (Harper Co.): Deep and moderately deep, nearly level to sloping silt loams, on uplands.
Minor Soils: Breaks - Alluvial land, Minco, and Ruella soils.

Pond Creek silt loam (Woods Co. Okla.): Moderately heavy, smooth upland soils.
Minor Soils: Nash, Kay, Reinach, and Foard soils.

Crisfield^{35} - Port^{35} - Zenda^{10} Association (Harper Co.): Deep, nearly level fine sandy loams and silt loams, on flood plans and low terraces.
Minor Soils: Brazos, Gerlane, Minco, Shellabarger, and Port soils and Slickspots.

Minco-Pond Creek Association (Harper Co.): Deep, nearly level, gently sloping and sloping silt loams; on uplands.
Minor Soils: Bethany, Farnum, and Port soils.

Typic Ustolls, Ustalfs, and Ustochrepts, Thermic

139: Haplustalfs - Argiaquolls: Clayey-Ustipsamments; level undulating; sandy and coarse loamy.

139-A: Naron^{40} - Pratt^{30} - Carwile^{20} Association (Rice Co.): Deep, nearly level to rolling soils that formed in moderately coarse textured and coarse textured eolian material and fine-textured alluvium; on uplands and terraces.
Minor Soils: Attica, Farnum and Clark soils.
(Parent Material: Dune sand and recent alluvium.)

Pratt^{40} -Carwile^{35} Association (Reno Co.): Deep, nearly level, imperfectly drained soils that have a clayey subsoil, and well-drained sandy, hummocky soils.
Minor Soils: Naron^{20}, and Tivoli^{5} soils.

Naron^{73} - Carwile^{15} Association (Edwards Co.): Deep, nearly level to gently sloping, well-drained and somewhat poorly drained loamy soils on uplands.
Minor Soils: Slickspots^{12}, Attica, Farnum, and Tabler soils.

Part of the Attica^{49} - Pratt^{35} - Carwile^{9} Association (Edwards Co.): Deep, nearly level to undulating, well-drained and somewhat poorly drained loamy and sandy soils on uplands.
Minor Soils: Naron^{7}, Brazos, and Plevna soils.

Pratt^{75} - Carwile^{20} Association (Pratt Co.): Undulating loamy fine sands that have a sandy subsoil, and nearly level or gently sloping fine sandy loams that have a clayey subsoil.
Minor Soils: Naron and Tivoli soils.

139-B: Carwile^{38} - Farnum^{32} - Tabler^{20} Association (Rice Co.): Deep, nearly level to gently undulating soils that formed in moderately coarse textured eolian material and fine-textured alluvium; on uplands and terraces.
Minor Soils: Attica, Drummond, and Naron soils.
(Parent Material: Dune sand and recent alluvium, and in the Sanborn Formation)

139-C: Dillwyn^{50} - Tivoli^{35} Association (Rice Co.): Deep, nearly level to hilly soils that formed in coarse-textured eolian materials; on terraces and uplands.
Minor Soils: Pratt, Carwile, and Plevna soils.
(Parent Material: Dune sand).

Elsmere^{75} - Tivoli^{15} Association (Reno Co.): Deep, nearly level, imperfectly drained, sandy soils and excessively drained, hilly, sandy soils.
Minor Soils: Plenva soils.

139-C:
(Cont) Pratt^{60} - Tivoli^{40} Association (Edwards Co.): Deep, hummocky and duny, well-drained and excessively drained, sandy soils on uplands.

Part of the Attica - Pratt - Carwile Association (Edwards Co.):

Tivoli^{55} - Pratt^{40} Association (Pratt Co.): Duny and hummocky, loose fine sands and loamy fine sands that have a sandy subsoil.
Minor Soils: Carwile soils.

Pratt^{35} - Brazos^{30} - Tivoli^{15} Association (Harper Co.): Deep and moderately deep, nearly level, undulating and hummocky loamy fine sands and fine sands; on low terraces and uplands.
Minor Soils: Carwile, Crisfield, Kanza, Ruella and Shellabarger soils.

140: Haplustalfs - Ustipsamments - Ustorthents: Level-rolling; sandy and coarse-loamy.

140-A: Mansic - Mansker - Otero Association (Ford-Meade Co.)

151: Ustochrepts - Argiustolls - Haplustalfs: Level to rolling; loamy and clayey shallow soils.

151-A: (Clark Co.)

151-B: Abilene - Potter Association: Smooth and rolling, mixed dark soils of the High Plains.
Minor Soils: Albion soils and rough broken land.

151-C: Weymouth-Cottonwood - Vernon Association: Rolling and undulating, reddish brown soils of the low plains with a friable subsoil.
Minor Soils: Fairview, Rusk, Grant, Reineck, and Yakola soils.

151-D: Guinlan^{45} - Woodward Association (Harper Co.): Shallow and moderately deep, nearly level, gently sloping and sloping loams on uplands.
Minor Soils: Brazos, Crisfield, Gerlane, Ruella, and Shellabarger soils.

Psamments

181: Psamments: Undulating-rolling; sandy.

181-A: Soils of the Sandhills: Tivoli - Vona - Pratt Associations:

Tivoli Association (Kearny Co.): Soils of the Sandhills, strongly undulating, hummocky, and choppy.
Minor Soils: Vona soils.

Tivoli - Vona Association: (Finney Co.): Soils of the Sandhills, deep, loose fine sands in choppy dunes.
Minor Soils: Otero fine sandy loams.

Pratt - Tivoli Association (Gray Co.): Hummocky and undulating, deep soils of the sand hills.

Pratt^{49} - Tivoli^{29} - Ortello^{22} Association (Ford Co.): Nearly level, undulating or hummocky deep soils that are well drained or excessively drained.

Tivoli^{97} Association (Ford Co.): Loose, rapidly permeable, strongly hummocky fine sands.
Minor Soils: Active dunes^{3}.

Vona - Tivoli Association (Morton Co.): Rolling sandy land.

Vona - Tivoli Association (Seward Co.): Rolling sandy soils on uplands.
Minor Soils: Otero, Mansic, and Blown-out land.

D: <u>Soils on Major Flood Plains and Bordering Terraces</u>

D-A: Soils of the Valley of the Arkansas River, and Valleys of the Pawnee River Drainage:

Bridgeport - Las - Las Animas Association (Kearny Co.): Soils in the Valleys of the Arkansas River and Bear Creek.
Minor Soils: Bayard, Bowdoin, Sweetwater, Lincoln, Tivoli-Vona, and Church soils.

Las - Las Animas Association (Finney Co.): Soil in the Valley of the Arkansas River.
Minor Soils: Bridgeport, Bayard, Sweetwater, and Lincoln soils.

Las Animas - Leshara - Lescho Association (Gray Co.): Nearly level, deep and shallow, well-drained and somewhat poorly drained loamy soils in the Valley of the Arkansas River.
Minor Soils: Lincoln, Sweetwater, and Bridgeport soils.

Dale - Leshara - Las Animas Association (Ford Co.): Nearly level, loamy alluvial soils that have a fluctuating water table and some saline-alkaline spots.
Minor Soils: (Dale - Humbarger - Canadian)[60], and (Leshara, Las Animas, Lincoln)[29] soils, Alluvial land and slickspots.

Las Animas, Las, Sweetwater, Bowdoin, and Lincoln Association (Hamilton Co.): Valley of the Arkansas River.

Roxbury[61] - Bridgeport[10] Association (Hodgeman Co.): Deep, nearly level, well-drained to moderately well-drained loamy soils on low terraces and flood plains.
Minor Soils: Broken alluvial land, Detroit, Hord and Ness soils.

D-B: Canadian[39] - Kaski[18] - Platte[15] Association (Rice Co.): Deep, nearly level soils that formed in moderately coarse textured to moderately fine textured alluvium over sand; on terraces and flood plains.
Minor Soils: Lesho, Waldeck, Plevna, Dillwyn and Tivoli soils.

Canadian - Dale[70] Association (Reno Co.): Deep nearly level, loamy soils of the flood plains and low stream terraces.
Minor Soils: (Vanoss, Lesho)[15], Slickspots, Wann, and Platte soils.

D-C: Detroit - Humbarger - Hobbs - Muir Association (Saline Co.): Deep, nearly level soils on terraces and flood plains.

Roxbury[24] - Altree[16] - Hord[11] Association (Ellis Co.): Deep, nearly level to strongly sloping, well drained soils that have a loam to silty clay loam subsoil; on flood plains stream terraces and valley sides.
Minor Soils: Alluvial land, Anselmo, Boel, New Cambria, Wann, Detroit, Holdrege, Inavale, McCook, and Munjor soils.

Detroit[45] - Hobbs[25] Association (Harvey Co.): Deep, nearly level, moderately well-drained to well-drained silty clay loams and silt loams on flood plains.
Minor Soils: Ladysmith, Naron, Farnum, and Lesho soils, Slickspots and broken alluvial land.

D-D: Chase[30] - Osage[25] Association (Chase Co.): Nearly level, deep soils that have a subsoil of silty clay; on flood plains and low terraces.
Minor Soils: Reading[24] Ivan[8], Solomon, and Kahola soils.

Appendix A. North Dakota

Soil Association/Soil Subgroup Code

Udic Borolls and Aquolls

1: Agriborolls - Eutroboraff; undulating to rolling; fine-loamy and clayey.

1-A: Kelvin - Bottineau [(80-90)] Association: (Bottineau County): Undulating to rolling; surface drainage undeveloped; numerous depressions and small lakes.
Minor Soils: Buse[(5-15)], Parnell, Tetonka [(10-20)], organic soils (peat).

B: Rolla-Kelvin (Bottineau County): Nearly level to gently sloping and undulating to rolling; surface drainage is into depressions.
Minor soils: Bottineau[10].

3: Argiborolls - Haploborolls;level-undulating; fine-loamy.

3-A: Forman[(45-60)] - Aastad[(20-35)] Association (Sargent County): Well-drained and moderately well-drained, nearly level and undulating soils in loamy glacial till, prismatic blocky subsoil, many enclosed depressions and potholes, generally less than 5 acres in size.
Minor soils: Buse, Hamerly[(5-15)], (Tetonka, Parnell)[10], Cresbard, La Prairie, Lamoure, and Zell.

4: Argiborolls - Haploborolls; undulating to hilly; fine-loamy.

4-A: Forman-Buse Association (Sargent County): Well-drained to excessively drained, undulating and rolling soils in loamy glacial till.
Minor soils: Aatad. Tetonka, Parnell.
AWC* .17; less than 35% slope.

5: Argiborolls - Haploborolls - Natriborolls: level; clayey and fine-silty.

5-A: Overly-Beardon Association (Sargent Co.): Nearly level to very gently undulating, occassionaly poorly drained depressions.
Minor soils: Gardena, Glyndon, Colvin, and Perella, Hamerly, Svea. Parent material: water-laid silty clay loams and silt loams.

Overly-Fargo Association (Sargent County): Moderately well-drained soils to poorly drained soils in old silty and clayey lake sediments.
AWC .17

*AWC = available water capacity

6: Calciaquolls; level; fine-silty; saline

6-A: Bearden-Glyndon Association (Walsh County): Moderately saline association. Deep, nearly level, somewhat poorly drained and moderately well-drained, silty and loamy soils that are saline.
Minor soils: Colvin, Perella, Non-saline Bearden, Glyndon.

7: Calciaquolls - Haploborolls; level; coarse-silty and fine silty.

7-A: Gardena - Overly Association: Well-drained soils in old, silty and clayey lake sediments, nearly level and slightly depressional areas
Minor soils: Tetonka, Bearden, and Glyndon soils.
AWC .15

B: Gardena - Glyndon Association (Sargent County): Moderately well-drained soils in old silty lake sediments; deep, nearly level soils.
Minor soils: Borup, Perella, Tetonka, Overly, and Hecla.
AWC .14

C: Gardena - Spottswood - Wessington Association: Well-drained loamy soils underlain by sands and gravel.
Minor soils: Hecla, Maddock, Borup, Stirum, Arveson.
AWC .14

Gardena^{30} - Glyndon^{25} Overly^{20} Association: Level, moderately well-drained and somewhat poorly drained, medium textured soils in old glacial lakebeds.
Minor soils: Aberdeen, Exline.

D: Embden^{40} - Glyndon^{40} - Egeland^{10} Association (Cass County): Nearly level, well-drained or somewhat poorly drained loams and fine sandy loams.
Minor soils: Gardena, Eckman.

Overly - Gardena Association (Ransom County): Nearly level, moderately well-drained loams to silty clay loams.

E: Gardena^{50} - Glyndon^{30} - Eckman^{5} Association (Cass County) : Nearly level, well-drained to somewhat poorly drained loams.
Minor soils: Embden, Renshaw, Egeland.
Parent material: Medium textured lake sediments.

F: Bearden^{30} - Overly^{30} - Fargo^{30} Association (Cass County): Nearly level, moderately well-drained to poorly drained silt loams and clays.
(Fargo is more poorly drained than the Bearden and Overly soils.)
Parent material: Moderately fine textured or fine textured lake sediments.

Aberdeen Association (Cass County): Nearly level, somewhat poorly drained silty soils that have a clay pan.

G: Lankin[46] - Gilby[35] Association (Walsh County): Deep, nearly level to gently sloping, somewhat poorly drained and poorly drained loamy soils.
Minor soils: Towner, Antler, Rockwell, Tonka.

H: (See 7-G)

I: Glyndon[73] - Gardena[14] Association (Walsh County): Deep, nearly level to gently sloping moderately well-drained and somewhat poorly drained loamy soils.
Minor soils: Borup, Colvin, Perella.

J: Bearden[65] - Overly[28] - Association (Walsh County): Deep, nearly level to gently sloping, somewhat poorly drained and moderately well-drained silty soils.
Minor soils: Colvin, Perella, Fargo.

Bearden[70] - Glyndon[26] Association (Walsh County): Deep, nearly level, moderately well-drained and somewhat poorly drained calcareous clayey and loamy soils.
Minor soils: Perella, Saline Bearden, Glyndon.

Overly[64] - Bearden[26] - Fans Association. Deep, nearly level, moderately well-drained and somewhat poorly drained silty and clayey soils on alluvial fans.
Minor soils: Fairdale, La Prairie.

K: (Bottineau Co.)

L: Gardena-Glyndon Association (Bottineau Co.)

M: (Roltte Co.)

N: Overly- earden Association (Tower Co.)

O: Gardena-Glyndon Association (Pembina Co.)

P: Glyndon Association.

8: Calciaquolls - Haploborolls - Argialbolls; level; fine-loamy and clayey.

8-A: Hamerly[30] - Svea[24] - Barnes[23] - Association (Walsh Co.): Deep, nearly level to rolling, somewhat poorly drained to well-drained loam soils.
Minor Soils: Vallers, Tonka, Manfred, Parnell

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Cresbard[60] - Hamerly[20] - Svea[15] Association (Walsh Co.): Deep, nearly level, moderately well-drained and somewhat poorly drained loamy soils:
Minor soils: Vallers, Tonka, Parnell.

B: Hamerly-Svea-Barnes Association (Cavalier Co.):

C: Hamerly-Svea-Tetonka Association(Rolette and Cavalier Co.):

D: Hamerly-Barnes-Tetonka Association (Tower and Cavalier Co.):

E: Hamerly-Barnes-Tetonka Association (Tower and Cavalier Co.):

9: Haplaquolls - Calciaquolls; level; clayey and fine-silty; vertic.

9-A: Hegne[74] - Fargo[20] Association (Walsh Co.): Deep, nearly level to gently sloping, poorly drained clayey soils.
Minor soils: Grano.

B: Wahpeton - Cashel - Fargo Association (Walsh Co.): Deep, nearly level to gently sloping, moderately well-drained to poorly drained clayey soils on flood plains and low terraces.

C: Fargo-Bearden Association (Bottineau Co.)

D: Fargo-Bearden Association (Pembina Co.)

E: Fargo-Bearden Association (Pembina Co.)

F: Hegne-Fargo Association (Grand Ford Co.)

G: Fargo Association (Tr[illegible] and Cass Co.)

10: Haploborolls; level; f[illegible] oamy over sandy or sandy-skeletal and fine-loamy.

10-A: Renshaw[35] - Brantford[29] - Sioux[12] Association (Walsh Co.): Shallow, nearly level to steep, excessively drained and well-drained loamy soils underlain by sand and gravel.
Minor soils: Arvilla, Coe, Vang, and Divide

B. Walsh[60] Association (Walsh Co.): Deep, level to sloping, well-drained and moderately well-drained loamy soils formed in shaly alluviums.

C: Renshaw - Divide Association (Bottineau and Rolette Cos.):

D: Walsh-Brantford Association (Pembina Co.):

E: Kelvin-Bottineau Association (Cavalier Co.):

F: Fargo Association (Cavalier Co.):

G: Brantford Association (Ramsey Co.):

H: Renshaw-Divide Association (Eddy Co.):

I: Renshaw Association (Ransom Co.):

J: Renshaw-Hecla Association (Kiddler Co.):

12: Haploborolls: undulating-rolling; fine-loamy.

12A: Barnes[55]- Buse[30] Association (Walsh Co.): Deep, gently undulating to steep well-drained and excessively drained loamy soils on the Edenburg moraine.
Minor soils: Parnell, Tonka, Svea, Embden.

B: (Pierce and Benson Co.):

C: (Ramsey Co.):

D: (Stutsman Co.):

E: (Sheridan Co.):

14: Haploborolls - Calciaquolls; level-undulating; coarse-loamy

14-A: Emrick[45]-Larson[25] Association (Wells Co.): Level to undulating, moderately well-drained, medium textured, claypan soils on uplands.
Minor soils: Miranda, Heimdal, Tonka, Parnell.

Egeland-Embden Association (Wells Co.): Level to undulating, well-drained and moderately well-drained, moderate to coarse textured soils on sandy plains.
Minor soils: Letcher, Arvilla, Ulen, and Hamar.

B: See Emrick-Larson Association (14-A) (Wells Co.):

C: LaDelle[30]Association (Wells Co.): Level, well-drained, medium-textured soils on lacustrine plains.
Minor soils: (Emrick, Larson)[38], Overly[7], Exline, Renshaw, Aberdeen Heimdal, Egeland and Embden.

D: Heimdal[43] - Emrick[25]-Fram [26] Association (Wells Co.): Level to undulating, well-drained to moderately well-drained, medium textured soils on glacialfluvial materials.
Minor soils: Tonka, and Borup.

E: see (14-D).

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15: Haploborolls - Calciquolls; level-undulating; fine-loamy.

15A: Barnes[50]-Svea[35] Association (Sargent, Wells Ward, and LaMoure Cos.): Well-drained, undulating soils in loamy glacial till; prismatic-blocky subsoil.
Minor soils: Buse, Parnell, Hamerly, Tetonka, Vallers, Cresbard, Cavour, Tonka.
AWC .17

B: Barnes[55]- Svea[25]- Parnell[8] Association (Walsh Co.): Undulating to rolling, well-drained and moderately well-drained, medium-textured soils on glacial uplands; and poorly drained moderately fine textured soils in enclosed morainic depressions.
Minor soils: Buse, Cresbard, Cavour, Nutly, Grano, Colvin.

C: Svea[40]- Hamerly[25]- Barnes[20] Association (Cass Co): Nearly level to undulating, well-drained to somewhat poorly drained loam.
Minor soils: Buse, Vallers, Tetonka, and Parnell.

D: Renshaw[45]- Arvilla[20]- Lamoure [15] Association (Wells Co.): Level, somewhat excessively drained to poorly drained, moderately coarse textured to moderately fine textured soils on gravelly terraces and in outwash channels.
Minor soils: Colvin, Benoit, and Divide

E: Barnes-Svea Association: (see 15-A).

F: Barnes-Hamerly Association (Renville Co.):

G: (McHenry Co.) soils on glacialfluvial materials.
Minor solis: Tonka, and Boreys.

H: Bottineau Co.)

I: (Bottineau Co.)

J: Barnes-Svea Association (Rolette and Tower Cos.):

K: Barnes-Hamerly Association (Rolette and Tower Cos.):

L: Svea-Hamerly Association (Cavalier and Benson Cos.):

M: Cresbard-Barnes-Cavour Association (Cavalier and Benson Cos.):

N: Barnes-Hamerly Association (Ramsey Co.):

O: Barnes-Hamerly Association (Benson Co.):

P: Barnes-Hamerly Association (Benson Co.):

Q: Svea-Hamerly Association (Benson Co.):

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16: Haploborolls - Calciaquolls - Haploquolls; level; coarse - loamy and sandy.

16-A: Hecla-Renshaw Association (Sargent Co.): Well-drained sandy and loamy soils underlain by gravel and sand, and wet, loamy and clayey soils in depressions and ponded areas.
Minor soils: Sioux, Gardena, Glyndon, Maddock, Borup, Colvin, Perella, Stirum, Arveson.
AWC .14

B: Hecla-Hamar-Ulen Association (Ransom, Cass, and Richland Cos.): Nearly level and gently undulating, moderately well-drained to poorly drained sandy soils.
Minor soils: Embden, Tiffany, Arveson
AWC .19

C: Exline-Aberdeen Association: Solodized soils in old, clayey lake sediments; nearly level, often ponded soils due to restricted surface runoff and internal drainage.
Minor soils: Dimmick and Bearden
AWC .16

D: Embden-Hecla-Ulen Association (Walsh Co.): Deep, nearly level to sloping, moderately, well-drained and somewhat poorly drained loamy and sandy soils.

E: Embden-Glyndon Association (McHenry Co.):

F: Hecla-Hamar Association (Botteneau Co.):

G: Hecla-Hamar Association (Bottineau Co.):

H: Maddock-Barnes Association (Bottineau and Pierce Co.):

I: Hecla-Hamar Association (Pierce Co.):

J: Embden-Ulen Association (Rolete Co.):

K: Cresbard-Cavour Association (Pierce Co.):

L: Embden-Glyndon Association (Grand Forks Co.):

M: Hecla-Hamar Association (Eddy Co.):

N: Maddock-Barnes Association (Foster Co.):

O: Embden-Tiffany Association (Richland Co.):

P: Ulen-Hecla Association (Richland Co.):

Q: Ulen-Stirum Association:

R: Embden-Ulen Association

S: Maddock-Barnes Association:

T: Hecla-Hamar Association (Kiddler Co.):

18: Natriborolls; level-undulating; clayey and fine-loamy.

18-A: Barnes-^{50} Cresbard^{30} Association (La Moure and Dicky Cos.): Nearly level to undulating, medium-textured, well-drained soils and level moderately well-drained and somewhat poorly drained soils that are moderately deep to a clay pan; on glacial till plains.
Minor soils: Svea, Tonka, and Cavour.

B: Edgeby Association (La Moure and Dicky Co.): Nearly level to undulating, moderately well-drained and well-drained soils formed inglacial till; moderately deep and deep to shale.
Minor soils: Barnes, Cavour, Cresbard, Tonka, Exline.

<u>Typic Borolls and Ustrothents</u>

19: Argiborolls; level-undulating; fine-loamy

19-A: Williams^{70}- Noonan^{10} Association (Burleigh Co.): Nearly level to undulating, well-drained, medium-textured soil and moderately well-drained claypan soils on glacial till plains.
Minor soils: Niobell^{5}, Lehr, Parshall, Miranda, Parnell, Tonka.

B: Williams^{55}- Max^{25} Association (Burleigh Co.): Nearly level to rolling, well-drained, medium-textured soils on glacial till plains.
Minor soils: Arnegard, Lehr, Parnell, Tonka, Colvin.

C: Williams^{60}-Bowbells^{30} Association (Ward Co.): Well-drained and moderately well-drained, nearly level, very dark brown loamy soils formed in glacial till
Minor soils: Tonka, Parnell.

Williams^{60}- Niobell^{30} Association (Ward Co: Well-drained, nearly level loamy soils formed in glacial till.
Minor soil: Noonan^{10}.

D: Williams-Bowbells Association (Ward Co.): (See 19-C).

E: Williams Association (Divide Co.):

F: Williams Association (Williams Co.):

G: Roseglen Association (Divide Co.):

H: Williams-Cresbard Association (Divide Co.):

I: Cresbard-Cavour Association (Burke Co.):

J: (Foster Co.)

K: (McKenzie Co.)

L: Williams Association (Emmons and McIntosh Cos.):

M: Morton-Williams Association (Emmons and McIntosh Cos.):

20: Argiborolls-Argialbolls-Haploborolls: level-undulating; fine-loamy and clayey.

20-A: Barnes-Svea Association (McIntosh Co.):

21: Argiborolls-Haploborolls; level-rolling; fine-silty and fine loamy.

21-A: Agar-Williams-Zahl Association (McLean Co.):

B: Agar Association (Emmons Co.):

23: Argiborolls-Haploborolls-Ustorthents: level-rolling; fine-loamy.

23-A: Williams^{50}-Max^{25}-Zahl^{10} Association (Burleigh Co.); Nearly level to steep, well-drained medium-textured soils on glacial till plains. Depressions common.
Minor soils: Arnegard, Parnell, Tonka & Regan.

B: Lehr^{55}-Wabek^{13}-Manning^{12} Association (Burleigh Co.); Nearly level to steep, somewhat excessively drained and excessively drained, medium-textured and moderately coarse textured soils on outwash plains.
Minor soils: Tansem, Roseglen, Regan, Colvin, Harriet and Williams.

C: Oahe-Sious Association (Divide Co.):

D: Williams-Zahl Associations (Williams Co.):

E: Williams-Zahl Association (Divide Co.):

F: Oahe-Roseglan Association (Divide Co.):

G: Williams-Zahl Association (McLean and Mercer, Oliver Cos):

H: Williams-Zahl Association (McKenzie Co.):

24: Argiborolls-Natriborolls-Ustorthents; level-rolling; fine loamy.

24-A: Rhoades^{35}- Moreau^{10} Association (Bowman Co.): nearly level to gently sloping, deep and moderately deep, moderately well-drained and well-drained, loamy soils that have a claypan and clayey soils.
Minor soils: Absher, Amor, Arnegard, Belfield, Cabba, Doglum, Ekalaka, Flasher, Grail, Korchea, Rucley, Regent, Shambo, Stady, Vebar, Velva.

Rhoades[25]- Aosher[20] Association (Bowman Co.): Nearly level to gently sloping deep and moderately deep, well-drained and moderately well-drained, loamy soils that have a claypan.
Minor soils: Arnegard, Belfield, Boxwell, Cabbart, Chanta, Daglum, Fleak, Ekalaka, Grail, Glendine, Harve, Kremlin, Marmarth, Moreau, Rhame.

Promise-Moreau Association (Stark Co.): Deep or moderately deep, well-drained clayey soils, nearly level soils in uplands swales and on valley terraces, and soils of the uplands that have slopes between 2 and 9%.
Minor soils: Bainville and Midway

Rhoades-Promise-Moreau Association (Stark Co.): Deep to shallow, well-drained, loamy or clayey soils, nearly level to sloping soils.
Minor soils: Regent-Belfield.

B: Farland-Savage-Rhoades Associations (Stark Co.): Deep, well-drained or moderately well-drained, loamy or clayey soils, some of which have a claypan, nearly level soils on stream terraces.

C: Morton-Rhoades-Flasher Association (Billings Co.):
Minor soils: Arnegard, Patent, Moline, Bainville.

D: See 24-C.

E: Morton-Rhoades-Flasher-Bainville-Flasher-Patent Association (Billings Co.):

F: (Stark Co.):

G: Belfield[20]- Rhoades[20]-Amor Association (Bowman Co.): Nearly level to gently sloping, deep and moderately deep, well-drained and moderately well-drained, loamy soils and loamy soils that have a clay pan.
Minor soils: Arnegard, Cabba, Daglum, Flasher, Grail, Manning, Moreau, Reader, Regent, Parshall, Stady, Tally and Vebar.

H: Amor-Reeder-Cabba Association (Bowman Co.) Nearly level to strongly sloping, moderately deep and shallow, well-drained loamy soils.

I: Morton-Rhoades Association (Morton Co.):

J: Rhoades-Morton Association:

25: Argiborolls-Ustorthents: level-rollings, loamy.

25-A: Roseglen[20]- Tamsen[20]- Savage[15] Association (Burleigh Co.): Nearly level to rolling, well-drained, mainly medium-textured soils on lake plains and terrace.
Minor soils: (Belfield, Daglum).[8], Rhoades, (Liken, Parshell)[7], Temvik, Arnegard, Lehr, Straw, Weener.

Heil[35]- Rhoades[25] Association (Burleigh Co.): Level, poorly drained and moderately well-drained, mainly fine-textured soils in lake Basins and outwash channels.
Minor soils: Savage[20], Tansen, Roseglen, Parshall, Daglum, Belfield.

B: Mortons-Regent-Grail Association (Stark Co.): Deep, well-drained silty or clayey soils on uplands that are disected by swales and drainage ways.
Minor soils: Bainville.

C: Morton-Vebar-Arnegard Association (Stark Co.) Deep, well-drained, loamy and moderately sandy soils, nearly level to sloping, on uplands and in small drainage ways and swales in the uplands.

D. (Kidder Co.)

E: Morton-Williams Association (Morton Co.):

F: Morton Association (Oliver Co.)

G: Vebar Association (Oliver Co.)

H: Savage-Wade-Farland Association

I: Morton-Regent Association:

27: Argiborolls-Ustorthents; level-rolling, clayey and fine-loamy.

27-A: Morton Arnegard, Chama Association (Golden Valley Co.):
Minor soils: Bainville, Flasher.

B: Agar-Raber Association:

C: Raber Association:

30: Haploborolls-Argiborolls-Ustipsamments; level-rolling; loamy and sandy.

30-A: Parshall-^{40} Lihen^{20}- Flaxton^{10} Association (Burleigh Co.): Nearly level to rolling, well-drained, mainly moderately coarse textured soils on outwash plains and sand mantled uplands.
Minor soils: Livona, Harriet, Shaw, Rhoades.

B: Telfer^{35}- Lihen^{35}- Seroco^{10} Association (Burleigh Co.): Nearly level to hilly well-drained and excessively drained mainly coarse textured soils on sand mantled uplands.
Minor soils: Flaxton, Livona, Arveson, Temvik, Heil.

C: Colvin^{35}- Vallers^{25}- Lamoure^{15} Association (Ward Co.): Poorly drained, level, loamy soils formed in alluvium and glacial till.
Minor soils: Renshaw, Lehr, Divide, Benoit, Hamerly, Parnell.

Manning^{40}- Lihen^{30} Association (Ward Co.): Well-drained, nearly level to undulating moderately sandy soils formed in glacial outwash.
Minor soils: Telfer, Lehr, Wabek, Benoit.

D: Vebar-Williams Association (McKenzie Co.)

E: Vebar Association

32: Haploborolls-Ustorthents-Argiborolls; undulating-hilly; fine-loamy.

Buse^{45}- Barnes^{40} Association (La Moure and Logan Co.): Steep to rolling, excessively drained to well-drained, medium-textured soils on morainic hills; poorly drained soils in scattered closed depressions.
Minor soils: Svea, Nutley, Sioux, Renshaw, Parnell and Grano.

B: Sioux^{50}- Baines^{45} Association (Wells Co.): Hilly, excessively drained to well-drained, medium textured soils on gravelly terminal moraines.
Minor soils: Renshaw, Arvella

Barnes^{62}- Buse^{15} Association (Wells Co.): Rolling to hilly somewhat excessively drained and well-drained, medium textured soils on glacial moraines.
Minor soils: Parnell^{10}, Vallers, Sioux, Colvin, Lamoure.

C: Max^{40}- Williams^{30} Association (Ward Co.): Well-drained, rolling to strongly sloping, loamy soils formed in glacial till.
Minor soils: Zahl^{10}, Bowbells^{10}, Parnell^{10}.

Max^{40}- Zahl^{20} Association (Ward Co.): Well-drained, hilly loamy soils formed in glacial till.
Minor soils: Bowbells^{15}, Williams,^{15}, Parnell^{10}

Nutley[40] - Sinai[40] Association (Ward Co.): Well-drained, moderately well-drained, level to gently sloping, clayey soils formed in glacial lacustrine sediments.
Minor soils: Williams, Max, Zahl, Parnell

Wabek[60] - Association (Ward Co.): Excessively drained, rolling and hilly, moderately sandy soils formed in glacial outwash.
Minor soils: Manning, Max, Zahl

D: Zahl-Williams Association (Divide Co.):

E: Zahl-Williams Association (McHenry Co.):

F: Buse-Barnes Association (McHenry Co.):

35: Ustorthents-Argiborolls; undulating-steep; loamy; shallow.

35-A: Flasher[55] - Vebar[25] Association (Burleigh Co.): Rolling to steep, well-drained and excessively drained, mainly moderately coarse textured soils on sandstone uplands.
Minor soils: Sen, Werner, Williams

B: Sen[55] - Weiner[20] - Morton[10] Association (Burleigh Co.): Gently sloping to hilly well-drained, medium-textured soils on soft shale and siltstone uplands.
Minor soils: Arnegard, Daglum, Flasher, Rhoades.

C: Williams[45] - Vebar[15] - Flasher Association (Burleigh Co.): Gently undulating to steep, well-drained, medium-textured soils on glacial till and excessively drained, moderately coarse textured soils on sandstone uplands.
Minor soils: Arnegard, Grail, Regan, Sen, Werner

35D: Temvik[35] - Mandan[20] - Werner[15] Association (Burleigh Co.): Nearly level to steep, well-drained, medium -textured soils on terraces, and uplands. Minor soils: Linton, Sen, Arnegard, Flasher, Williams and Vebar.

E: Bainville-Flasher Association (Stark Co.): Shallow, excessively drained loamy or moderately sandy soils, sloping to steep
Minor soils: Vebar

Bainville-Midway Association: Shallow, excessively drained, loam or clayey soils; rolling to steep.
Minor soils: Moreau, Morton, Flasher

Bainville-Flasher Association (Billings Co.):

F: Vebar-Flasher Association (Bowman Co.): Nearly level to gently undulating moderately deep, well-drained and shallow, excessively drained, sandy and loamy soils.

G: Reeder-Brandenburg-Cabba Association (Bowman Co. and Slope Cos.): Gently sloping to strongly sloping moderately deep and shallow, well-drained and excessively drained, loamy soils.

H: Zahl-Williams Associaton (Montrail Co.)

I: Bainville-Zahl Association (Williams and Montrail Cos.)

J: Bainville-Morton Association

K: Bainville-Rhoades Association

L: Flasher-Bainville-Rhoades Association:

Borollic Aridisols and Torriorthents

44: Torriothents-Camborthids-Natrargids; undulating-hilly; loamy and clayey; shallow.

44-A Ekalaka-Rhame-Zeona Association (Bowman Co.) Nearly level to gently undulating, deep and moderately deep, well-drained, loamy soils and loamy soils that have a claypan and deep, excessively drained, sandy soils.

B: Dilts-Lisam-Shale Outcrop Association (Bowman Co.): Gently sloping to hilly, shallow well-drained, clayey soils and shale outcrops.

C: Rhame-Fleak Association (Bowman Co.): Nearly level to gently undulating moderately deep, well-drained, loamy soils, and shallow excessively drained, sandy soils.

Psamments

181: Psamments: Undulating-rolling; sandy

181-A: Valentine-Hecla Association (Sargent Co.): Sandy soils in a chopping area where differences in elevation are generally less than 10 feet. Minor soils: Arveson and Gannett.

Valentine Association (Sargent Co.): Sandy soils in a chopping area where differences in elevations are 20 to 40 feet.

B: Maddock-Hamar Association (Ransom and Richland Cos.): Gently undulating to hilly somewhat excessively drained to poorly drained, sandy soils
Minor soils: Hecla, Ulen.

Rockland

184: Badland-torriorthents: undulating-steep; loamy and clayey.

184-A: Rough broken land-Bainville-Patent Association (Billings Co.):

B: Cabbart-Alshir Association (Bowman Co.): Hilly to steep, shallow and deep moderately well-drained and well-drained, loamy soils and loamy soils that have a claypan.

Cabbart-Badlands-Yawdim Association (Bowman Co.): Steep to very steep, shallow, well-drained, loamy and clayey soils and bad land.

Soils of Major Flood Plains and Bordering Terraces

D-A: Harvelon -Lahler-Banks Association (Burleigh Co.): Nearly level, moderately well-drained and somewhat excessively drained, fine-textured to coarse textured soils on bottom lands
Minor soils: Lallie and Riverwash

B: Zahl^{35} - Max^{30} Williams^{20}- Velva^{15} Association: Well-drained, level to steep, loamy soils formed in glacial till and well-drained, level, loamy soils formed in alluvium.

C: Havre -Toby-Glendive Association: Nearly level, deep, well-drained loamy soils.

D: Havre -Farl nd-Banks Association (McKenzie Co.)

E: (Cavalier Co.)

F: Walsh-Edgeley -Buse Association:

G: (Foster Co.)

APPENDIX B

APPENDIX B

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Influence of Order of Entry on ΔR^2

John Claydon

When the independent variables in a regression problem are correlated with each other, the ΔR^2 of each variable (the amount by which R^2 increases with the addition of that variable to the equation) depends substantially upon the order of entry The general explanation is that when a group of independent variables are highly correlated they are "partially redundant", i.e. a subgroup of them can explain almost as much variance as the whole group, regardless of which ones make up the subgroup.

A small experiment was performed to investigate the impact of this phenomenon on ΔR^2, and to assess the validity of variable entry in regression without prior ordering. For Kansas Date Two, regressions of L5, L7, K1 and K2 were studied. These dependent variables were chosen because of their intrinsic relationship to crop development. For each of these dependent variables, the first three independent variables entered by the Forward Regression Algorithm were entered in all six possible orders.

Regression of K2 experienced the greatest variability in ΔR^2 values due to order of entry. The independent variables AWC, GAMS, and JANTEMP* were correlated with each other in the range of .45 to .70. Their correlations with K2 were -.655, -.051, and -.551, respectively. From these correlations it can be hypothesized that AWC and JANTEMP are roughly equal in their ability to account for the variability in K2, with GAMS explaining much less of the variablity. By this hypothesis, the following two orders of entry would be of nearly equal validity, but of greater validity than other orders (ΔR^2 are in parentheses).

(A) AWC (.429), JANTEMP (.017), GAMS (.282)

(B) JANTEMP (.304), AWC (.142), GAMS (.282)

The Forward Regression Algorithm, however, selected

(C) AWC (.429), GAMS (.287), JANTEMP (.013)

When the algorithm is applied after entering JANTEMP first, (B) is chosen. Thus, while AWC and JANTEMP have nearly equal correlations with K2, and thus are almost equally likely to be chosen for first entry, these two alternatives result in JANTEMP being entered third with ΔR^2 = .013 or first with ΔR^2 = .304.

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*See the list of variable definitions at end of this appendix.

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It can also be noted that:*

(1) JANTEMP ΔR^2 ranged from .30 to .35 for three of the six regressions, and had a ΔR^2 of .01 (approximately) for the remaining three;

(2) AWC ΔR^2 ranged from .14 to .71, both of these extremes being for second position, after GANS and JANTEMP, respectively;

(3) GANS ΔR^2 was .28 (approximagely) for three regressions, and less than .05 for the remaining three regressions.

*Comparisons of the ranges of ΔR^2 for JANTEMP and GANS, over all six regressions, seems to support the previous hypothesis that JANTEMP belongs before GANS. On the other hand, GANS had much higher ΔR^2 than JANTEMP in both orderings after AWC; and the F-values** for choosing the second variable were 160 for GANS and 5 for JANTEMP.*

The variability of ΔR^2 with order was less for L7 than for K2, but greater than for L5 and K1. Forward Regression chose, in order:

(D) LTGSDD (.646), ROBT (.047), SCANANG (.059). (ΔR^2 are in parentheses.)

Their correlations with L7 were -.804, -.472, and -.176, respectively, which clearly support the order chosen. Consider, however, changing the order of the last two:

(E) ROBT (.047), SCANANG (.059)

(F) SCANANG (.005), ROBT (.102).

Here we see a strange phenomenon (more marked in L5 and K1): a variable could receive a larger ΔR^2 when moved back to a later entry than specified by Forward Regression.

L5 and K1 were very highly correlated (r = .942) and thus had the same variables entered by Forward Regression in the same order. LTGSDD is clearly the most important; its correlation with L5 was -.711, while the other correlations with L5 were near zero. When LTGSDD was entered first, ΔR^2 equalled .505; when entered second ΔR^2 equalled .787 and .577; when entered third, ΔR^2 equalled .826. Similarly, in the case of K1, LTGSDD has lowest ΔR^2 when entered first. This phenomenon is related to the inter-correlations among the independent variables, but at present cannot be explained in more specific terms.

**See tables at end of appendix.*

***After first entering the variable with the highest absolute value of correlation with the dependent variable, the Forward Regression Algorithm in SPSS computes, for each remaining variable, a ratio of mean sums of squares ("F-value") appropriate for a test of significance. The variable with the highest F-value is entered second; then the process is repeated.*

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Happily in the case of K1, SCANANG, which is entered third by Forward Regression, had the same very small ΔR^2 regardless of its order of entry. LAND was not quite so well behaved. In the case of L5 the ΔR^2 ranged from .003 to .254, and in the case of K1 ΔR^2 ranged between .065 and .131.

On the basis of the four cases examined, it can be concluded that the order chosen by Forward Regression was generally, but not always, reliable, and that ΔR^2 can be an unreliable measure of the relative accountability of spectral variance when the signature predictor variables are significantly correlated.

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TABLE B.1

DEFINITIONS OF NAMES OF INDEPENDENT VARIABLES:

LANDS:	CULTIVATED AREA PERCENT
AWC:	SOIL AVAILABLE WATER HOLDING CAPACITY
LTGSDD:	LONG TERM AVERAGE GROWING SEASON DEGREE-DAYS
ROBT:	ROBERTSON BIONUMBER
GAMS:	24xAWCx(SUM GROWING SEASON PRECIPITATION) - (SUM GROWING SEASON EVAPOTRANSPIRATION)
JANTEMP:	AVERAGE TEMPERATURE, JANUARY 1976
SCANANG:	100X (TANGENT OF LANDSAT SCAN ANGLE)

TABLE B.2: LANDSAT BAND 7 (L5) R^2 = .834

	LAND	LTGSDD	SCANANG
	(1).003	(2).787	(3).044
	(1).003	(3).826	(2).005
	(2).285	(1).505	(3).044
	(2).005	(3).826	(1).003
	(3).254	(1).505	(2).075
	(3).254	(2).577	(1).003
SIMPLE CORRELATION WITH L5	-.053	-.711	.052

CORRELATIONS:

	LAND	LTGSDD	SCANANG
LAND			
LTGSDD	-.034		
SCANANG	.280	.294	

TABLE B.3: LANDSAT BAND 7 (L7) R^2 = .867

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	LTGSDD	ROBT	SCANANG
	(1).646	(2).047	(3).059
	(1).646	(3).102	(2).005
	(2).470	(1).223	(3).059
	(2).619	(3).102	(1).031
	(3).467	(1).223	(2).062
	(3).467	(2).254	(1).031
SIMPLE CORRELATION WITH L7	-.804	-.472	-.176

CORRELATIONS:

LTGSDD			
ROBT	.761		
SCANANG	.294	-.151	
	LTGSDD	ROBT	SCANANG

TABLE B.4: <u>KAUTH BAND 1</u> (K1) R^2 = .844

	LAND	STGSDD	SCANANG
	(1).068	(2).752	(3).024
	(1).068	(3).776	(2).000
	(2).131	(1).639	(3).024
	(2).065	(3).776	(1).003
	(3).116	(1).689	(2).039
	(3).116	(2).725	(1).003
SIMPLE CORRELATION WITH K1	-.261	-.830	-.055

CORRELATIONS
SAME AS L5

TABLE B.5: KAUTH BAND 1 (K2) $R^2 = .728$

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	AWC	GAMS	JANTEMP
	(1).429	(2).287	(3).013
	(1).429	(3).282	(2).017
	(2).713	(1).003	(3).013
	(2).142	(3).282	(1).304
	(3).373	(1).003	(2).352
	(3).373	(2).051	(1).304
SIMPLE CORRELATION WITH K2	-.655	-.051	-.551

CORRELATIONS:

AWC			
GAMS	.679		
JANTEMP	.699	.456	
	AWC	GAMS	JANTEMP

APPENDIX C

APPENDIX C: EVALUATION OF "SOUTH DAKOTA OVER ESTIMATION PROBLEM" (Reproduced from Hay, 1977)

UCB was requested to review the problem of winter wheat over estimation in 1977 South Dakota segments. In response to that request, three members of the UCB staff spent a week at JSC evaluating the problem.

As part of the evaluation, the UCB analysts labeled Procedure 1 - type 2 dots for each of ten South Dakota segments for which there was a significant overestimation. The winter wheat estimate for the ten segments was then recalculated using the UCB labeled type 2 dots to bias correct the machine stratification produced from LACIE AI labeled type 1 dots. A comparison of wheat estimates generated from UCB labeled type 2 dots versus LACIE AI labeled type 2 dots is shown in Table C.1. Estimates for five segments were lowered (2 appear to be significant), one segment was unchanged, and four segments were raised using the UCB labels. Ground data was not available at the time for a complete evaluation of the results.

A major difference in the analysis procedures employed by UCB analysts was the heavy utilization of historical county agricultural statistics. Use of the statistics allowed the UCB analysts to determine that no significant amount of winter wheat (approximately less than 2%) had historically been planted within the counties in which the test segments fell. Full frame data and other ancillary data did not indicate that any major recent land use changes were occurring so that no significant changes of winter wheat proportions from the historical averages were expected. Thus a working hypothesis of not significant winter wheat proportions for these segments was adopted prior to actual dot interpretation. Pasture and alfalfa were found to be major confusion crops within these segments when no at-harvest acquisitions were available, and it was difficult to place a decision boundary between wheat and pasture without these acquisitions. Use of the historical statistics aided in fixing a workable decision boundary for some segments that had a somewhat decent acquisition history.

The main conclusions drawn from review of the South Dakota problem were:

1. The main confusion crops for winter wheat in South Dakota were pasture and alfalfa. This confusion would have been somewhat less if an at-harvest acquisition had been available. There was some confusion with spring small grains when the acquisition history was poor.

2. The winter wheat proportions within the segments examined, were too small (less than 5%) to allow the analyst to develop a reliable decision logic.

3. Historical county agricultural statistics can be useful in flagging segments for which significant measurement problems can be expected.

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Crop Reporting District	Segment No.	# Dots Labeled	W/W*	W/O	O/O	O/W	Winter Wheat Est. 1974 County	Winter Wheat Est. 1976 County	Winter Small Grains (Wheat & Rye) AI Est. %	Winter Small Grains (Wheat & Rye) UCB** Est. %
NW	1486	110	Ø	Ø	105	5	1.0%	1.3%	0.0%	3.2%
	1670	92	7	1	79	5	1.0%	1.8%	9.0%	15.2%
WC	1682	52	6	4	42	Ø	5.3%		3.7%	2.1%
C	1686	133	1	7	94	9	1.4%	1.1%	8.0%	14.0%
	1687	97	17	12	49	19	4.4%		25.5%	33.3%
SC	1694	91	20	1	68	2	9.0%	9.7%	18.0%	18.0%
NE	1498	209	4	30	175	Ø	.2%	1.2%	16.2%	1.4%
EC	1784	209	Ø	5	204	Ø	.03%	.1%	2.2%	0.0%
SE	1807	209	Ø	5	203	Ø	.01%	.06%	2.5%	0.0%
	1808	76	2	12	61	1	1.4%	1.6%	12.0%	3.0%

* Analyst Label/UCB Label

** Recalculated using type 2 dots to Bias Correct machine estimate using LACIE AI type 1 dot labels.

Table C.1 Comparison of South Dakota winter wheat estimates using type 2 dots labeled by LACIE AI's and UCB AI's.

4. *Past years data would have been beneficial in eliminating some winter wheat with pasture confusion, however, most segments were new for 1977 and past seasons acquisitions were not available.*

UCB would recommend for similar measurement situations that:

1. *Historical agricultural county statistics be utilized more heavily in the analysis procedure to help set analyst decision boundaries or as checks to flag possible problem segments.*

2. *Past years data be utilized in areas of significant winter wheat with pasture/alfalfa confusion.*

3. *Spectral aids be made available before the analysis is to take place.*

4. *More informaiton on the development and condition of confusion crops such as pasture and alfalfa gathered and made available to the analyst.*

5. *Sample segment allocation for each wheat type (winter, spring) be based on that specific wheat type proportions and not on total small grains proportions.*